Topographic and Geologic Survey of Pennsylvania

RICHARD R. HICE, State Geologist

REPORT No. XII

Glass Manufacture

AND THE

Glass Sand Industry

OF PENNSYLVANIA

BY

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TOPOGRAPHIC AND GEOLOGIC SURVEY COMMISSION

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LETTER OF TRANSMISSION.

———

Beaver, Pa., December 10, 1917.

Hon. G. W. McNees, Chairman,

Sir:—

I herewith submit the manuscript and illustrations of a report on Glass Manufacture and the Glass Sand Industry of Pennsylvania, by Dr. Charles R. Fettke, Assistant Professor in Geology and Mineralogy in the Carnegie Institute of Technology, Pittsburgh, and recommend its publication as Report Number 12 of this Survey.

The preparation of this report was authorized in 1914 and most of the field work relating to the sand deposits of the State was done during the summer of that year. It was the intention to rapidly push the work to a completion during the season of 1915, but the failure of appropriations brought all active work to a close. At that time Dr. Fettke proposed to complete the office and laboratory work and the preparation of the manuscript at his own expense and on his own time, an offer which was accepted. Under these conditions the work was not pushed and we are to be congratulated that it has been completed at so early a date.

The report speaks for itself and it will be a most valuable contribution to the literature of the glass industry, and more especially to the glass sand industry, not only in this State, but in other states as well. It is a distinct contribution to the economic geology of the State.

Respectfully submitted,

RICHARD R. HICE,

State Geologist.

GLASS MANUFACTURE AND THE GLASS SAND INDUSTRY OF PENNSYLVANIA

INTRODUCTION.

Glass sands are sands that are almost entirely made up of quartz grains, found in nature either in the form of loose, unconsolidated sediments, or in deposits in which the individual grains are more or less thoroughly bound together by some cementing agent. Such sands are now used almost exclusively in the manufacture of glass as the source of the silica which is the major constituent of this useful substance. While deposits of sands and sandstones occur both widely and abundantly in nature, deposits that are sufficiently free from other constituents than quartz grains, so that they can be employed in the manufacture of glass, especially of the better grades, are, comparatively speaking, of rare occurance.

Pennsylvania holds a leading position among the states of the Union in the production of this grade of sand as well as in the manufacture of the various kinds of glass products into which it enters. It was, therefore, thought a description of the glass sand deposits would be of interest and of value to the citizens of Pennsylvania. In connection with the preparation of such an account the necessary qualifications of glass sands for different kinds of glass were also investigated, as well as the methods of manufacture of the different glass products, since many difficulties encountered which are charged by the manufacturer to the sand used, may often be traced to some other source. For this reason a brief description of all materials used and the methods of manufacture employed are also incorporated in this report.

The preparation of this report was undertaken for the Topographic and Geologic survey Commission of Pennsylvania, under the supervision of Richard R. Hice, the State Geologist. The chemical and screen analyses and petrographic examinations of the sands were performed in the geological and mineralogical laboratories of the Carnegie Institute of Technology of Pittsburgh. For assistance rendered in carrying on the work the writer wishes to express his thanks to the owners and officers of the various Companies producing glass sand in the State, who practically without exception

allowed him entire freedom in examining their plants and quarries and furnished him with all the information desired in regard to their operation. Especial thanks are due to W. P. Stevenson, of Mc-Veytown, for an account of the early history of the glass sand industry in Mifflin county. The writer also wishes to thank the officers of the Thomas Carlins Sons Co., the Lewistown Foundry and Machine Co. and the Phillips and McLaren Co., for data in regard to the cost of machinery and other equipment used in connection with sand plants; to Geo. W. Cochran of the Ohio Valley Clay Pot Co., H. A. Eatherton of the Findlay Clay Pot Co., Chas. O. Grafton of the Gill Clay Pot Co., J. G. Quay of the Beaver Valley Pot Co., and A. S. Zoppi of the Buckeye Clay Pot Co., for information in regard to the manufacture of clay pots; and the officers of the American Window Glass Co., the Fidelity Glass Co., the H. C. Fry Glass Co., the Hazel-Atlas Glass Co., the Jeanette Glass Co., the McKee Glass Co., the Pittsburgh Plate Glass Co., and the Tarentum Glass Co., for permission to inspect their plants. Dr. S. R. Scholes, of the Mellon Institute of the University of Pittsburgh, also furnished the writer with valuable information in regard to the properties necessary for glass sands used in the manufacture of flint glass and the methods employed in the manufacture of glass pots.

The examination of the various glass sand quarries in the State of Pennsylvania upon which this report is based were made during the summer and fall of 1914.

CHAPTER I.

DEFINITION AND COMPOSITION OF GLASS.

It is a rather difficult matter to give a definition of glass that will hold good for all cases. For example, if one takes such a property as transparency, which the term glass at once suggests, one finds that while most glasses possess it, there are a number which do not, some are not even translucent, and yet they are true glasses. The same holds true for any of the characteristics of glass. There is, however, one property which all substances that may be classified as glass possess in common, that is an amorphous structure.

By amorphous structure is meant an entire absence of any molecular arrangement in a particular substance. This distinguishes glasses from most mineral and other inorganic bodies, which on solidifying usually take on a definite molecular or crystalline structure, which gives them certain optical and other physical properties, characteristic for each substance. These properties will usually vary along different directions in the same substance. For example, in the case of a crystal of quartz a ray of light travelling through it in the direction of the vertical axis will behave differently from one passing through it at right angles to that axis, due to the nature of the internal structure of the crystal. In the case of a piece of glass light will be transmitted through it in the same manner in all directions. This is due to the fact that there is an entire absence of any structure which would affect the ray differently in different directions. Liquids and colloid bodies also show this same indefinite arrangement of their molecules.

There is still another characteristic which also emphasizes the close relationship between glass and ordinary liquids. When a glass is cooled from the molten or liquid condition it gradually becomes more and more viscous until finally the solid state is reached. At no particular stage in this process is there a definite amount of heat liberated, the loss of heat being an entirely uniform one from start to finish. In the case of crystalline substances, however, this is not true, for when they are cooled from their liquid state a certain temperature will be reached at which a definite amount of heat will be released, and the temperature instead of dropping uniformly will remain stationary for a time, until the solid state has been assumed. It is at this point that the crystalline structure is taken by the molecules. This is accomplished by the liberation of energy in the form of heat. In contrast, therefore, to the

crystalline structure of true solids, glasses may be considered to be highly viscous or congealed liquids.

The chemical composition of glasses as a rule is a rather complex one. In most cases it consists of one or more anhydrides or acidic oxides, in combination with several basic oxides. In the ordinary glasses of commerce silica (SiO_2) is the anhydride present, while sodium oxide (Na_2O), lime (CaO), potassium oxide (K_2O) and lead oxide (PbO) are the most common basic oxides. In addition to these, however, several other acidic oxides, such as boron trioxide (B_2O_3) and phosphoric anhydride (P_2O_5), and a large number of other basic oxides besides those mentioned above, enter into the composition of certain special glasses, such as those used for optical purposes and in chemical laboratories. The various compounds formed by the combination of these oxides are present in the glass in solution in one another, for, as has been before stated, glasses may be regarded as being simply rigid solutions.

One other distinction besides that of amorphous structure must be made to distinguish glasses from such products of the clay industry as porcelain, which, so far as their outer appearance are concerned, resemble certain glasses very closely. In the case of the glasses it is necessary that the materials which go to make up the final product are first brought to the molten condition by fusion, and then allowed to assume the solid form by cooling, being given their desired shape while still plastic. In the case of porcelain, or other clay wares, the raw materials are mixed with water to a paste and this paste is molded into the desired form while cold. It is then heated to a high temperature to harden it, but not sufficiently high to fuse it.

The following analyses will illustrate the chemical composition of some of the more common kinds of glass:

Window Glass.

	American.	American.	Belgian.	English.	English.	English.	English.	French.	French.	German.	German.
	(1)	(7)	(1)	(1)	(2)	(4)	(4)	(1)	(2)	(1)	(5)
SiO_2, ____	72.26	71.00	69.48	71.40	72.00	69.6	72.5	69.65	71.9	72.68	71.23
Al_2O_3, ___	} 1.42	1 to 2	2.59	1.90	2.00	{ 1.4	1.00	} 1.82	1.4	1.06	1.70
Fe_2O_3, ___	}					{ .4*	.4*	}			
MgO, ____			.26							.26	.20
CaO, ____	13.34	13.00	13.40	12.40	13.00	13.4	13.1	13.31	13.6	12.76	16.39
Na_2O, ___	14.01	14.00	14.55	15.00	13.00	15.2	13.0	15.22	13.1	13.25	10.78
Total,	101.03	100.00	100.28	100.70	100.00	100.0	100.0	100.00	100.0	100.00	100.30

*Including MnO_2.

Plate Glass.

	Ameri-can. (1)	Ameri-can. (7)	Bel-gian. (1)	Eng-lish. (1)	Eng-lish. (4)	Eng-lish. (4)	Eng-lish. (4)
SiO_2,	71.2	71.0	72.4	78.64	72.0	73.2	75.2
Al_2O_3,	1.0	1.0 to 2.0	_____	2.68	.5	.4	.9
Fe_2O_3,							
Mgo,							
CaO,	14.2	13.0	13.2	6.09	8.5	13.6	6.9
Na_2O,	13.9	14.6	14.4	11.63	19.0	12.8	17.0
K_2O,	_____	_____	_____	1.34	_____	_____	_____
Total,	100.3	100.0	100 0	100.38	100.0	100.0	100.0

Plate Glass—Continued.

	French. (1)	French. (2)	German. (5)	German. (6)	German. (6)
SiO_2,	72.1	71.80	70.58	77.00	73.00
Al_2O_3,	_____	1.26	1.01	_____	_____
Fe_2O_3,	_____	.14	.80	_____	_____
MgO,					
CaO,	12.2	15.70	16.07	7.40	15.20
Na_2O,	15.7	11.10	11.77	15.50	11.80
K_2O,					
Total,	100.0	100.00	100.23	99.90	100.00

Lime Flint Glass.

	Ameri-can. (1)	French. (1)	French. (6)	French. (6)	German. (1)	German. (6)	Russian. (6)
SiO_2,	73.96	69.6	77.3	72.0	75.61	78.4	74.7
Al_2O_3,	.44	5.2	trace	4.5	1.01	.2	.4
Fe_2O_3,						.2	.1
MgO,	.41	_____	_____	_____	_____	_____	_____
CaO,	13.94	13.0	6.4	6.4	7.38	7.1	8.8
Na_2O,		3.0	16.3	17.0	_____	13.9	15.7
K_2O,	10.85	8.0	_____	_____	11.39	_____	_____
PbO,	.18	_____	_____	_____	4.84	_____	_____
MnO,	_____	_____	_____	_____	_____	.2	.2
Total,	99.78	99.8	100.0	99.9	100.23	100.0	99.9

Bottle Glass.

	Ameri-can. (1)	Ameri-can. (3)	Ameri-can. (3)	Ameri-can. (3)	Ameri-can. (3)	Ameri-can. (3)	Eng-lish. (4)	French. (1)
SiO₂, _____	69.82	62.69	76.11	71.34	71.02	70.06	58.4	63.34
Al₂O₃, _____	} 2.58	{ 7.95	1.84	2.53	1.61	3.27	2.1	4.72
Fe₂O₃, _____	}	{ *	*	*	*	*	8.8	4.42
MgO, _____	----------	3.82	.93	.62	1.38	4.00	----------	----------
CaO, _____	7.82	10.23	12.46	11.60	5.95	4.60	18.6	21.34
Na₂O, _____	18.28	15.31	8.66	13.91	20.04	18.07	9.9	4.17
K₂O, _____	1.50	----------	----------	----------	----------	----------	1.8	2.01
Total, _____	100.00	100.00	100.00	100.00	100.00	100.00	99.6	100.00

*Not reported.

Lead Flint Glass.

	Ameri-can. (1)	Ameri-can. (5)	Ameri-can. (7)	Bel-gian. (1)	Eng-lish. (1)	French. (1)	(2)
SiO₂, _____	63.76	53.70	54.00	53.70	51.40	52.41	53.17
Al₂O₃, _____	} .90	{ 1.12	----------	} 1.07	----------	.96	{ ----------
Fe₂O₃, _____	}	{ ----------	----------	}	----------		{ ----------
MgO, _____	.31	----------	----------	----------	----------		
CaO, _____	----------	.17	----------	.59	----------	.77	----------
Na₂O, _____	} 12.86	{ .70	----------	9.12	----------	10.37	----------
K₂O, _____	}	{ 7.36	11.00	.30	9.40		13.88
PbO, _____	21.93	37.02	35.00	34.91	37.40	. 35.24	32.95
Total, _____	99.76	100.07	100.00	99.69	98.20	99.75	100.00

(1). Glass. Robert Linton, Mineral Industry for 1899, Vol. 8, pp. 234-263.
(2). Glass. Sir Edward Thorpe, Dictionary of Applied Chemistry, Vol. 2, pp. 719-739. (1912).
(3). The Requirements of Glass for Bottling Purposes. R. L. Frink. Trans. American Ceramic Society, Vol. 15 (1913), pp. 706-727.
(4). The Commoner and Glass Worker, Vol. 21 (1899 , No. 11. Quoting from English Pottery Gazette.
(5). Handbuch der Glasfabrikation, Fifth Edition, Dr. E. Tscheuschner, Weimer, 1885.
(6). Die Glasfabrikation, Second Edition. Raimund Gerner, Vienna, 1897.
(7). Glass. James Gillinder. Industrial Chemistry, edited by Allen Rogers and Alfred B. Aubert, New York, 1913, pp. 313-328.

An inspection of the foregoing analyses shows there may be considerable variation in the chemical composition, even in the case of glasses used for the same purpose, and yet all of them will possess the properties necessary for that particular use. This is true of all the ordinary varieties of glass, such as window, plate, bottle, lime flint and lead flint for tableware, but does not hold good in the case of special glasses, such as those used for optical purposes, where small variations in chemical composition are often accompanied by considerable differences in optical properties. In the manufacture of this kind of glass, therefore, great care must be exercised to obtain the proper composition.

Even in the case of the ordinary glasses of commerce, however, although a certain amount of variation in composition is permissable,

there are certain limits to which these variations in the molecular ratios or proportions of the various oxides composing the glass must be confined, or the glass will not show the necessary resistance to the action of the air, moisture, acids or other decomposing agents, and will be deficient in other physical and chemical properties. The molecular ratios of the various oxides are obtained by dividing the percentage composition of each oxide by its molecular weight.

From a comparison of the analyses of a large number of different samples of glass Tscheuschner derived the following formula for the best or "normal glass":

$$x\ R^1{}_2\ O,\ y\ R''\ O,\ 3\left(\frac{x^2}{y} + y\right)SiO_2$$

In this formula $R^1{}_2O$ represents the sum of all the molecular ratios of the alkalies present in the glass, namely Na_2O and K_2O, while the $R''O$ represents that of the alkaline earths, CaO, MgO and BaO, and the metallic oxides sometimes present such as PhO, ZnO and Fe_2O_3. In the case of Al_2O_3 there is still some doubt as to whether it plays the part of a metallic or an acidic oxide in the glass. Dralle claims that satisfactory results may be obtained by classing it with the silica in the above formula, even when the percentage of Al_2O_3 present is fairly large. X represents the coefficient obtained by adding the molecular ratios of the alkalies, while y represents the one obtained by adding those of the alkaline earths and other metallic oxides present. The coefficients x and y must fall within certain limits in order to give the glass the necessary properties to make it desirable. According to Dralle a good lime-soda glass will be obtained if when the coefficient y is made equal to 1.0, x falls between 0.5 and 1.0 and the coefficient of SiO_2 is equal to $3(x^2+1)$.

For window glass Tscheuschner states that x can vary between 0.6 and 1.0 when y is made equal to 1.0, and for lime flint between 0.8 and 1.5 and give good results. In the case of the potash glasses more silica should be used, so that instead of $3(x^2+1)$ the coefficient of SiO_2 should be $4(x^2+1)$.

The alkali glasses melt more readily than those high in lime, but the latter are cheaper. The above formulas can also be used for lead glasses, but on account of their greater fluidity, the amount of silica specified by the above formulas may be exceeded. Likewise lead glasses very low in alkalies may be made, which are very durable on account of the slight solubility of the lead silicate formed.

Gelstharp and Parkinson have carried out a number of interesting experiments which have enabled them to prepare a triaxial diagram in which the approximate practical limits of variations in composition for lime-soda glasses are shown, especially those used

in the manufacture of plate glass, but also applicable to bottle glass, table ware and window glass, where lime, soda and silica are the principal constituents present, and other oxides, such as those of potassium, magnesium, barium, zinc, lead, manganese, iron, aluminum and boron are practically absent. This diagram is reproduced in Plate I.

Below the line joining $2Na_2O.SiO_2$ and $CaO.SiO_2$ basic slags and infusible mixtures of silicates and bases are formed. Between this line and the one joining $Na_2O.SiO_2$ and $2CaO.3SiO_2$ transparent glasses are formed only on very rapid cooling, otherwise only opaque crystalline masses result. Between the latter line and the one joining $Na_2O.5SiO_2$ and $2CaO.3SiO_2$ transparent glasses proper, including those of technical importance appear, while above this area only opalescent opaque glasses result on slow cooling. In the area representing the composition of the transparent glasses, the good mechanically strong and durable ones may be separated by a line on the left cutting off those containing sodium in excess of 22% of the silica content, and below by a line joining $Na_2O.2SiO_2$ and $CaO.2SiO_2$. Below this latter line the glasses formed are, for the most part, mechanically weak, have not sufficient resistance to withstand the action of dilute acids, water or the atmosphere and tend to devitrify or crystalize readily. The desirable glasses formed are represented by the shaded portion of the diagram. It is divided into two parts by a line drawn from the apex of the triangle to a point which represents a molecular ratio of soda to lime of 2 to 1. Only in the small portion to the left can soda ash (Na_2CO_3) alone be the source of the alkali. In the portion to the right of this line, according to Gelstharp and Parkinson, salt cake (Na_2SO_4) must be used, at least in part, or white scum and flakes will be produced.

In the diagram, in order to determine the percetange composition of any glass, such as one represented by the point "A," measure off the distance A-b to the 10% line for Na_2O, using the scale of the diagram, to get the percentage of Na_2O. In a similar manner measure off the distance A-c to the 10% line for CaO, to get the CaO percentage and the distance A-d to the 70% line for SiO_2 to get the SiO_2 percentage. In the above case the results are 13.8% CaO, 13.2% Na_2O and 73.0% SiO_2. If the percentage composition of a lime-soda glass is known its position on the diagram may be found by reversing the operation as above outlined.

100% Na₂O

2Na₂O·SiO₂

Na₂O·SiO₂

Na₂O·2SiO₂

Na₂O·5SiO₂

100% SiO₂

2Na₂O·CaO

CaO·2SiO₂

2CaO·3SiO₂

CaO·SiO₂

100% CaO₂
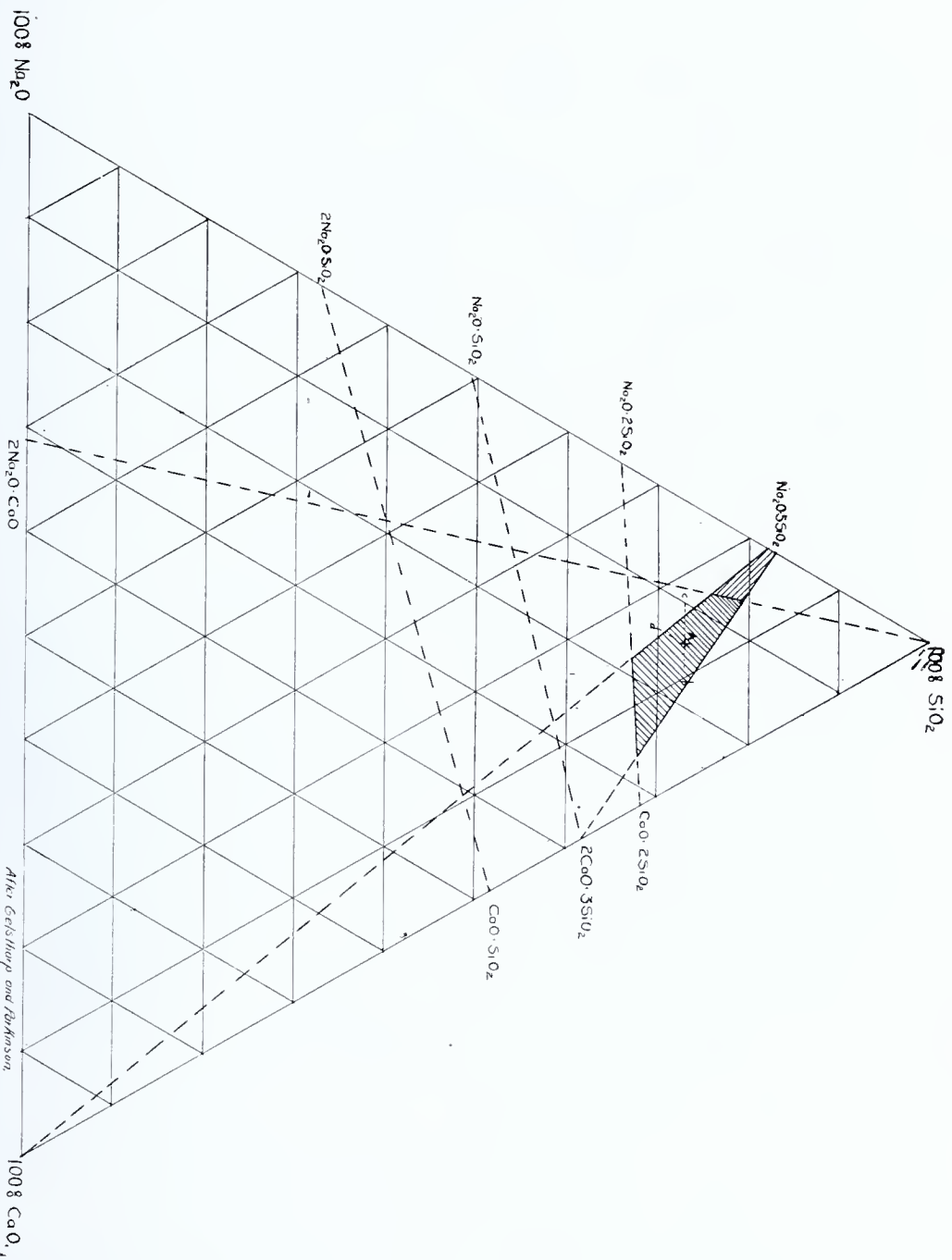
PLATE I.

Gelstharp and Parkinson's Diagram.

After Gelstharp and Parkinson.

CHAPTER II.

CLASSIFICATION OF GLASSES.

In as much as there are a large number of different substances available for supplying the acid and basic oxides in glass, and no definite proportions are necessary, but the relative amounts may vary considerably and still give glasses of technical value, a wide range of glasses is possible. On examination, however, it will be found that the great majority of those actually used will belong to one or another of a few main types.

A great many different classifications of glasses have been proposed, based on different factors, such as chemical composition, technical use, method of manufacture, etc. On the following pages several of these are given. The first one is based chiefly on chemical composition, the second two on technical use, and the last one on method of manufacture.

Thorpe's Classification of Glasses.[1]

A. Glasses in which the acid is entirely silica, combined with two or more bases, one of which is an alkali.
    1. Lime-Soda Glass.—This type is very extensively employed for window glass, chemical glassware, bottles, etc. The precise composition varies in different cases. CaO is sometimes partially replaced by BaO, and a small amount of alumina is generally present.
    2. Alumina-Lime-Soda Glass.—This is chiefly used for beer, wine and spirit bottles, owing to its strength and insolubility.
    3. Lime-Potash Glass.—Generally known as Bohemian glass. Used for hollow ware.
    4. Lead-Potash Glass, Lead Flint.—Used extensively in the manufacture of hollow ware, bottles and optical glass.
B. Glass containing other acids in addition to silica.
    1. Boro-Silicate Crown.—Like type A-1 above, with silica partially replaced by B_2O_3. Used for optical glass, thermometer tubing, and laboratory ware.
    2. Boro-Silicate Flint.—Like type A-4 above, with silica partially replaced by B_2O_3. Used for optical glass, in the manufacture of enamels, "strass" for imitation gems, etc.
    3. Phosphor Glass.—In which the silicon is partially replaced by phosphorus.
C. Glass containing no silicon: "Borate" and "phosphate" glasses. Occasionally used in optical work.
D. Simple silicates consisting of silica and alkali only. This type is soluble in water, and is known as soluble or water glass.
E. Quartz glass, consisting of pure silica in the amorphous state.

Knapp's Technical Classification.[2]

I. Lead Free Glasses.
    A. Bottle glass with its varieties.
        a. Common bottle glass, composed of SiO_2, a little Al_2O_3, and Fe_2O_3, CaO, and Na_2O.
        b. Glass for druggists' bottles, made of the same materials, though usually with only a very little Al_2O_3 and Fe_2O_3.
        c. White bottle glass, for bottles, drinking glasses, tubes, etc., made of SiO_2, CaO, and Na_2O or K_2O, usually the former.
    B. Window glass, composed of SiO_2, a very little Al_2O_3, CaO, Na_3O, and very rarely some K_2O.
    C. Plate glass, made of SiO_2, a very little Al_2O_3, CaO, Na_2O, or very rarely K_2O. Distinguished from window glass by the fact it is more nearly colorless.

1. Glass, Dictionary of Applied Chemistry, by Sir Edward Thorpe, Vol. 2., (1912) pp. 719-739.
2. Handbuch der glass fabrikation by Dr. E. Tscheuschner, 5th edition, Weimar, 1885.

II. Glasses containing lead.
    D. Crystal glass, for cut glass, made of SiO_2, PbO, and K_2O.
    E. Flint glass (most of the optical glasses), made of SiO_2 or B_2O_3, or both, more PbO than the crystal glass, and K_2O.
    F. Flint glass (most of the imitation gems), made of SiO_2, a greater lead content than either D or E, and K_2O, colored with different metallic oxides.
    G. Enamels, made of SiO_2, PbO and Na_2O. Rendered opaque with ZnO or Sb_2O_3.

Linton's Commercial Classification.[3]

1. Polished plate.—Embraces all glass cast upon a smooth table, rolled to the required thickness with a roller, annealed, and then ground and polished.
2. Rough Plate.—Embraces all glass cast as above, but not ground and polished. The principal varieties are ribbed plate, colored cathedral, rough plate, wire glass and heavy rough plate for skylights.
3. Window Glass.—Embraces glass blown in cylinders, and afterwards cut, flattened out and polished while hot. Chiefly used for glazing, pictures, mirrors, etc.
4. Crown Glass.—Embraces glass blown in spherical form and flattened to a disk shape by centrifugal motion of blow pipe. A little is made at the present time for decorative purposes.
5. Green Glass.—Embraces all the common kinds of glass, and is not necessarily green in color. It is used in the manufacture of bottles, carboys, fruit jars, etc.
6. Lime Flint.—Embraces the finer grades of bottles used for the prescription trade, tumblers, certain lines of pressed table ware, and many novelties.
7. Lead Flint.—Embraces all the finest products of glass making, such as fine cut glass, table ware, optical glass, artificial gems, etc.

Benrath's Classification, According to Method of Manufacture.[4]

1. Glasses which are cooled rapidly and which are not given any definite shape, as water glass, smalt, and fritts.
2. Glasses which are only worked after very slow cooling and complete solidification, such as optical glass and artificial gems.
3. Glasses which are cooled moderately and in a still semi-fluid, viscous state are given their shape. Green glass or bottle glass, semi-white hollow glass ware, white hollow glass ware, tumbler glass, turbid and colored tumbler glass, milk or opal glass, cryolite glass, colored glass, lead crystal, tubes and bead glass, and sheet or window glass.
4. Glasses in whose formation the more fluid condition of the glass at a higher temperate is made use of, such as rolled and pressed glass.

3. Glass, by Robert Linton. The Mineral Industry for 1899, Vol. VIII, New York, 1900, pp. 234-263.
4. Handbuch der glass fabrikation by Dr. E. Tscheuschner, 5th edition, Weimar, 1885.

CHAPTER III.

CHEMICAL PROPERTIES OF GLASS.

It has already been shown that glass may be considered as a congealed solution of a number of chemical compounds, usually silicates of various metallic elements, in one another. The bases most commonly employed are the alkalies, sodium and potassium, the alkaline earths, calcium, magnesium, barium, and rarely strontium, and the oxides of lead and in minor quantities of alumina and iron, the latter two being usually present as impurities in some of the ingredients used in the manufacture of glass. Many other metallic oxides in addition to those enumerated above are occasionally used to impart special properties to the glass. The acid radical usually consists of silica, but in some special glasses the boric and phosphoric acid radicals are also employed to replace the silica, in whole or in part. Inasmuch as the chemical composition plays an important part in determining both the chemical and the physical properties of the resulting glass, with this wide range in possible ingredients a great many different types of glasses may be produced.

Although molten glass if cooled sufficiently rapidly takes on an amorphous structure, during this cooling a certain point will be reached where there will be a tendency for certain of the constituents to crystallize out. If crystallization actually takes place, it is known as devitrification.

The facility with which this crystallization will occur depends largely upon the chemical composition of the glass. In some cases it sets in so readily that it is almost impossible to prevent it, while in other cases the glass must be kept at the proper temperature for hours before any crystallization can be induced.

As the glass is cooled below the temperature at which devitrification tends to take place the liquid becomes more and more viscous and the tendency of the molecules to arrange themselves in a definite crystalline structure is not sufficient to overcome the resistance which the liquid presents and an amorphous structure results.

There exists then a critical range in temperature for every glass through which the crystallizing forces have the greatest tendency to overcome the internal resistance of the glass and if the glass is not cooled sufficiently rapid devitrification sets in at this point. Below this temperature this tendency becomes less and less marked, until at ordinary temperatures the internal resistance prevents it entirely.

As has already been stated the chemical composition plays an important role in devitrification, glasses of certain compositions tending to devitrify much more readily than others. This tendency, therefore, places a limit on the range of substances and their relative pro-

portions which can be employed under the conditions ordinarily met with in the manufacture of glass. This subject will be discussed somewhat further under the various ingredients employed in the manufacture. Among other things excess of lime in the glass increases its tendency to devitrify. Alumina, on the other hand, when present in small quantities tends to prevent it.

Most glasses are exceedingly stable and chemically inert at ordinary temperatures, which is an important property in determing their use for many purposes. None of them are, however, by any means perfect in this respect. The degree of stability depends largely upon the composition of the glass.

The resistance of glass to atmospheric influence is a matter of great importance in the case of window, plate and other glasses exposed to its attack. This action is a very complex one involving attack by water, carbon dioxide, and other gasses and vapors often present in the atmosphere, combined with constant variation in temperature.

Pure water will attack all glass to a certain extent by dissolving some of the alkali present, but in the cold the action is practically negligible except in the case of very poor glass. With rise in temperature, however, this action increases. Superheated water, that is water under steam pressure, is a very active corroding agent, and even the best glasses can only resist its action for a limited time. For the guage glasses of steam boilers, therefore, especially durable glasses are required. In the case of certain glasses this action is not confined to the surface, but the water penetrates into the mass of the glass and combines with it, probably forming hydrates with some of the silicates present. This action sometimes takes place where a poor grade of glass is stored in a damp place for a considerable length of time.

Alkaline solutions attack glass much more readily than pure water. They first combine with the silica of the glass, thus setting free the bases, which are carried away in solution. In this way a fresh surface of glass is exposed to attack.

The ordinary dilute acids on the other hand, with the exception of hydrofluoric, have relatively little action on glass, much less than pure water. The strong acids also, with the same exceptions, have practically no action on the silicate glasses. Where boric or phosphoric acid replaces part of the silica, however, this does not hold true. Hydrofluoric acid rapidly decomposes all types of glasses by combining with the silica to form volatile fluorides. Highly basic glasses are less readily attacked than those rich in silica. The action on an ordinary lime-soda glass is shown by the following equations:

$$CaSiO_3 + 3H_2F_2 = SiF_4 + CaF_2 + 3H_2O$$
$$Na_2SiO_3 + 3H_2F_2 = SiF_4 + 2NaF + 3H_2O$$
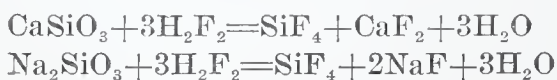
On account of this property, hydrofluoric acid is used extensively in etching glass in the decoration of hollow ware.

Carbon dioxide, a gas which is always present in small quantities in the atmosphere, is also instrumental in decomposing glass, especially in the presence of moisture. The action is probably a more or less indirect one. Some of the water vapor in the atmosphere condensing on the surface of the glass as a thin film of moisture, exerts its dissolving action and a certain amount of alkali is extracted from the glass in the form of the hydroxide. Carbon dioxide is readily absorbed by this alkaline solution and the carbonate, either of sodium or potassium, depending on the composition of the glass, is formed. If the moisture evaporates again in the case of soda glass a thin coating of minute sodium carbonate crystals will remain behind on the surface of the glass giving it a dull, dimmed appearance. These may be removed by washing, the silica set free by the reaction being removed at the same time mechanically. Potassium carbonate, on the other hand attracts moisture so readily from the atmosphere that it would not under ordinary conditions crystallize out in the dry, solid state, and therefore a potash glass would not be as liable to exhibit this dim surface, although it would be attacked just as readily as a soda glass.

Rosenhain also calls attention to the fact that the films of alkaline solution which are formed on the surface of the glass, especially the less resistant varieties, form a ready breeding ground for certain kinds of bacteria and fungi, whose growth occurs partly at the expense of the glass itself. Specks of organic dust falling upon the glass give rise to local decomposition probably for the same reason. It has been noticed that the presence of small proportions of boric acid in some glasses renders them more resistant to attack from atmospheric agencies and much less sensitive to the effects of organic dust particles lying upon their surface. This may be due to the fact that small quantities of boric acid entering into solution in the film of surface moisture exert an anticeptic action which prevents the activity of bacterial and fungoid growth.

Numerous efforts have been made to devise satisfactory means for determining the relative resistance of a glass to atmospheric agencies without actually awaiting the results of experience through a long interval of time. One of the earliest of those proposed consists in exposing the surface of the glass to the vapour of hydrochloric acid. For this purpose some concentrated hydrochloric acid is placed in a glass or porcelain basin and strips of the glass to be tested are placed across the top of the basin, the whole being covered with a bell jar. After several days the glass is examined and usually the less stable glasses show a dull, dimmed surface as compared with the more stable ones. Another test proposed by Tscheuchner is to take several

samples of glass, pack them in the same crucible with pulverized ferrous sulphate and heat for a time to dark red heat. The ferrous sulphate liberates vapors of SO_3 which attack the glass. A comparison may be made by washing, drying, and weighing the different samples. A somewhat more satisfactory test than either of the above depends upon the fact that aqueous ether solutions react readily with the less stable kinds of glass, and if a suitable dye, such as iod-eosin, is dissolved in the water-ether solution when one of the less stable glasses is immersed in the solution, a strongly adherent pink film will form on it. The density and depth of color of this film will be a measure of the stability of the glass. The best grades of glass will remain free from any colored film even on prolonged exposure. Dr. Zschimmer has devised a test somewhat different from the above. This depends on the fact that the disintegrating action of moist air can be very much accelerated if both the moisture and the temperature of the air surrounding the glass be considerably increased. The samples of glass are, therefore, exposed to a current of air saturated with moisture at a temperature of about 80 degrees C or 176 degrees F. in a specially arranged incubator, usually for several days. Different glasses will show different appearances after being subjected to this treatment. The most stable glasses will remain entirely unaffected, less stable ones will show small specks where they were attacked, while the least stable ones will show a dulled surface.

All these tests give one only a relative idea in regard to the stability of different glasses and it is somewhat of a question whether they will always fall into the same relative order under the influence of ordinary atmospheric action that they do under the influence of the agents used and under the conditions imposed upon them in the tests.

Almost all glasses undergo changes when exposed for a long time to the action of strong light, especially sunlight, or ultra-violet light. These changes are usually made manifest by a change in color. For example, many glasses containing manganese although at first they may be practically colorless, after prolonged exposure to the light will assume a purple or violet tinge. This may often be seen in the case of the glass globes surrounding arc lights or street lamps.

The chemical behavior of different glasses at high temperature, while they are still in the molten condition, is of great importance to the manufacturer. Some glasses will attack the clay vessels in which they are contained much more readily than others.

CHAPTER IV.

PHYSICAL PROPERTIES OF GLASS.

The two most valuable physical properties of ordinary glass are transparency and rigidity at ordinary temperatures, passing to plasticity at high temperatures. These in addition to hardness and resistance to chemical change make glass such a useful substance. As in the case of the chemical properties of glass, the physical properties also vary with the chemical composition, so that glasses of different compositions may show widely different physical properties.

The density of glass varies with the molecular weight of its constituents. Thorpe gives it from 2.25 in the case of the lightest borate glasses to 6.33 in the case of the heaviest lead and barium glasses, the average for lime-alkali glass being 2.5 and for lead flint 3.00. Trautwine gives the specific gravity of common window glass as 2.52 and according to Kent the specific gravities of the ordinary lime-soda glasses of commerce vary from 2.5 to 2.75, and of lead flint from 2.88 to 3.14.

Attention has already been called to the fact that transparency is one of the important physical properties of most glasses. Colorless glass transmits practically the whole of the visual spectrum in equal amounts, but the whole of the light falling on it does not pass through. A certain portion is reflected at the surface of entry, another at the surface of exit, while a still further portion is absorbed during its passage through the glass. In the case of the purest colorless glasses the portion absorbed is very small and practically uniform for rays of different wave lengths, as far as the visual spectrum is concerned, but it is never entirely so. Even these glasses will, therefore, show a slight color, usually a blue or green tint, if considerable thicknesses are examined. The best plate glass shows a slight greenish-blue tint, which is quite marked when the glass is viewed edgewise. Window glass, as a rule, has a decidedly deeper color.

The optical properties of glass are very sensitive to variation in chemical composition and the methods of treatment employed in their manufacture. One of the most essential properties of optical glass is homogeneity, that is the glass must have the same density throughout. This is a rather difficult thing to attain in glass and ordinary glass never possesses it, so that when a thick piece of such glass is examined the threads or layers of different densities can be recognized in the form of minute internal irregularities in the glass. These defects are known as striae or veins and they must be avoided in glass which is to be used for the better kinds of optical work. Special means are used to accomplish this.

Transparency and color are also of prime importance. A good optical glass should absorb as little light and be as nearly colorless as possible. This can only be accomplished by using very pure raw materials in the manufacture and clay pots which will not react with the glass in such a way as to introduce undesirable impurities.

The fundamental optical constant of each variety of optical glass is known as its index of refraction. Its value is obtained by dividing the sine of the angle of incidence by the sine of the angle of refraction. This ratio really represents the ratio of the velocity with which the light waves are propogated through the glass to the velocity with which they travel through the air. This ratio varies with the chemical composition of the glass and its physical condition, and also has a different value for light waves of different lengths. It varies directly with the specific gravity of the glass, a high specific gravity being accompanied by a high index of refraction while a low specific gravity gives a low index of refraction. The indices of refraction of different glasses used for optical purposes range from about 1.49 to 1.71.

Attention has already been called to the fact that light waves of different lengths will be refracted differently in passing through glass. This property of glass is known as dispersion. It is of extreme importance in optical work.

The lustre of glass depends largely upon its index of refraction and upon its ability to resist the action of atmospheric agents, for if the surface of the glass is attacked it will become dim and dull. The glasses with high indices of refraction have a more brilliant lustre than those with low ones.

Hardness is a property which is of some importance in many of the applications of glass. By hardness we mean the ability of the glass to resist abrasion. This property varies with the chemical composition and also with the rate at which the glass is cooled. As a general rule it may be said that glasses rich in silica and lime are hard, while those rich in alkilies, lead, or barium, are soft. Rapid cooling will produce a great increase in hardness even in comparatively soft glasses. No satisfactory method for measuring hardness has yet been devised.

The mechanical properties of glass are often of considerable importance, as in the case of handling large sheets of plate glass or sheet glass, also in the case of guage tubes for high pressure boilers and other instances where glass is called upon to withstand considerable pressure. These properties vary considerably with the composition and also with the manipulation during manufacture, more particularly the rate and condition of cooling. Kent quotes the following figures from Fairburn for the mean tensile and crushing strengths of ordinary glasses:

Tensile and Crushing Strengths of Glasses.

	Best flint glass.	Common green glass.	Extra white crown glass.
Mean specific gravity,	3.078	2.528	2.450
Mean tensile tsrength, pounds per sq. in. in bars,	2,413	2,896	2,546
In thin plates,	4,200	4,800	6,000
Mean crushing strength, pounds per sq. in. in cylinders,	27,582	39,876	31,003
In cubes,	13,130	20,206	21,867

The bars in the tensile strength tests were about ⅛ inch in diameter. The crushing tests were made on cylinders about ¾ inch in diameter and from 1 to 2 inches high and on cubes approximately one inch on aside.

Trautwine gives the ultimate tensile strength of glass as 2,500 to 9,000 pounds per square inch and the crushing strength as 6,000 to 10,000 pounds per square inch. In a series of special glasses investigated by Winkelmann and Schott at Jena the modulus of elasticity (Youngs modulus) varied from 3,500 to 5,100 tons per square inch, the value being largely dependent upon the chemical composition.

Glass is an exceedingly brittle substance at ordinary temperatures. Its brittleness increases with the rapidity at which it is cooled. Measureable ductility has not been observed in glass under ordinary conditions.

The electrical properties of glass are of considerable importance, as glass is frequently used in electrical appliances as an insulating medium. Its insulating properties vary greatly with the chemical composition. As the rule the harder glasses, that is those high in silica and lime, are the best insulaters, while soft glasses, such as those high in alkali and lead, are much poorer in this respect. As has already been stated glass tends to condense a thin film of moisture from the atmosphere upon its surface which attacks the glass to a certain extent, different glasses varying considerably in the degree to which they display this hygroscopic tendency. As a rule the softer glasses are much more hygroscopic than the hard ones, and in some cases the resulting film of surface moisture serves to lessen or even break down the insulating power of the glass by allowing the electricity to leak away along the film of moisture. In the case of appliances for static electricity, where very high voltages are dealt with, an attempt is sometimes made to avoid this leakage by varnishing the surface of the glass with shellac or some similar substance.

The thermal properties of glass although not of such general importance as the mechanical properties nevertheless have to be

taken into consideration in the case of a large number of uses to which glass is put. One of these properties is that known as thermal endurance, which measures the amount of sudden heating or cooling to which glass may be exposed without fracturing. This depends upon a number of factors, the chief of which are tensile strength and elasticity, and the relation between thermal conductiveity and expansion. An illustration will show how these operate in determining the thermal endurance. If a hot liquid is poured into a glass vessel, the material of the inner layer of glass expands or endeavors to do so, being restrained by the resistance of the central and outer layers of material which are still cold. The inner layer is, therefore, in a state of compression while the middle and outer layers are under tension. If this tension is sufficiently great the outer layers will fracture and the vessel will be shattered. A high coefficient of expansion and a low modulus of elasticity will both favor fracture, while a high tensile strength will tend to prevent it. The thermal conductivity of the glass will also affect the result, because the intensity of the tensile stress set up in the colder layer will depend upon the difference in temperature. The heat capacity, or specific heat of the glass, also has an influence on the thermal endurance, as heat will penetrate more slowly through a glass whose own rise in temperature absorbs a greater quantity of heat. The endurance is higher in glass rich in silica and low in lime and alumina, and is greatest in pure quartz glass, which is able to withstand extensive variations of temperature without fracture.

Glass is always a comparatively poor conductor of heat. The coefficient of thermal expansion varies considerably in different glasses. Trautwine gives the following linear expansion for glass for 1 degree F. rise in temperature.

> Glass rod 1 foot in 221,400 feet
> Glass tube 1 foot in 214,200 feet
> Glass crown 1 foot in 211,500 feet
> Glass plate 1 foot in 209,700 feet.

Rosenhain gives the limiting values for the cubical expansion per degree Centigrade as 37×10^{-7} for the lower and 122×10^{-7} as the upper limit. Thorpe gives the mean cubical expansion of soda-lime glass as lying between 0.000023 and 0.000027. The relative expansion becomes of great importance when two different glasses have to be fused together, as in the case of flashed glass and the decoration of glass by enamels. In most cases the expansion is not uniform and for the construction of instruments like thermometers, where such a defect introduces serious error, special glasses have to be made.

The fusibility of glass depends upon its chemical composition. This restricts the range of possible compositions of glasses which

can be manufactured on a commercial basis to those which can be obtained under the temperature of 1,600 degrees C., or 2,900 degrees F., as temperatures exceeding this cannot be produced in the ordinary type of furnace.

In working glass it cools so rapidly that a tension is developed between the outer and inner layers. The outside layer cools and hardens first, while the inside layers are still soft. When the inside layers cool and harden they tend to contract and draw away from the outer ones, but as the latter are already hard and rigid the result is not a contraction of the whole mass but the development of a tension between the layers, the amount depending upon the rapidity of the cooling. This tension makes the glass tough, hard and strong and gives it great thermal endurance as long as the surface is left unbroken. As soon, however, as the surface becomes scratched or broken, thus relieving the tension, the glass flies into fragments. For this reason glass intended for ordinary use must be cooled slowly so that the outside and the inside layers will cool nearly simultaneously and all tension between them avoided. This is known as annealing the glass and will be discussed in more detail in a later chapter.

CHAPTER V.

RAW MATERIALS OF GLASS MANUFACTURE.

The raw materials employed in the manufacture of glass may be divided into two groups:—those which on being melted together make up the glass substance itself and those which are used to bring about a change in the raw substances or the glass in any direction, but are not necessary for the formation of the glass substance itself.

The first group may again be divided into two classes of substances:—those which furnish the acidic ingredients of the glass and those which furnish the basic ones. There are a number of raw materials, however, which furnish both types. These will be taken up under the basic oxide yielding class. In the second group are included all materials for clarifying, decolorizing, and coloring glass.

ACID OXIDES.

Silica. SiO_2.

Silica is the most important constituent entering into the composition of glass. There is no glass in the technical sense which does not have silica as an important constituent. It can only be replaced to a small extent by other acidic oxides, which is done in the case of some of the glasses used for optical and other special purposes.

Silica, next to oxygen, is the most abundant element found in nature. It occurs in combination with oxygen as the oxide, SiO_2, in the form of such minerals as quartz, tridymite, chert, flint, chalcedony, and opal, and in combination with many of the basic oxides it enters into the composition of a large group of minerals known as the silicates. According to F. W. Clarke 59.85% of the earth's lithosphere consists of SiO_2.

For purposes of description the many forms of quartz may be divided into three groups, namely: vitreous, chalcedonic, and jaspery cryptocrystalline varieties. Besides quartz, silica also occurs in nature as the mineral tridymite, and combined with varying amounts of water as opal. The following list is that given in Dana's Manual of Mineralogy and Petrography. A few of the less common forms have been omitted by the writer.

Vitreous Varieties of Quartz. SiO_2.

Rock Crystal. Pure pellucid quartz. Specific gravity 2.65.

Amethyst. Purple or bluish violet, and often of great beauty. Color disappears on heating and is probably due to a little manganese. Specific gravity 2.65 to 2.66.

Rose Quartz. Pink or rose colored. Seldom occurs in crystals; generally in masses much fractured, and imperfectly transparent. The color fades on exposure to light. Probably colored by titanium or manganese. Specific gravity 2.65.

Yellow Quartz, or False Topaz. Light yellow pellucid crystals.

Smoky quartz. Crystals of a smoky tint; the color is sometimes so dark as to be nearly black and opaque except in splinters. The smoky color is due to some carbon compound. Specific gravity 2.65 to 2.66.

Milky Quartz. Milk white, translucent to nearly opaque, massive, and of common occurance. It is a constituent of many rocks. Often has a greasy lustre, and is then called greasy quartz. Specific gravity 2.64 to 2.66.

Aventurine Quartz. Common quartz spangled throughout with scales of golden yellow mica hematite, or goethite. Usually translucent, and gray, brown or reddish brown in color.

Ferruginous Quartz. Opaque, and either of yellow, brownish-yellow, or red color from the presence of iron oxide.

Chalcedonic Varieties.

Chalcedony. Translucent, massive, with a glistening and somewhat waxy lustre, usually of a pale grayish, bluish, whitish, or light brownish shade. Not found in crystals. Frequently nodular, mammillary, or stalactitic. Often occurs lining or filling cavities in amygdaloidal and other rocks. The cavities are little caverns into which siliceous waters have, at some period, filtered and deposited their silica.

Chrysoprase. Apple green chalcedony, colored by nickel.

Carnelian. Bright red chalcedony, of a clear, rich tint.

Sard. A deep brownish-red chalcedony, of a blood-red color by transmitted light.

Agate. A variegated chalcedony. The colors are distributed in clouds, spots, or concentric bands. These bands take straight, circular, or zigzag form.

Onyx. A kind of agate having the colors arranged in flat horizontal layers. The colors are usually light clear brown and an opaque white. When the stone consists of sand and white chalcedony in alternate layers it is called sand onyx.

Flint, Hornstone, Chert. Massive compact silica, of dark shades of smoky gray, brown or even black, feebly translucent, breaking with sharp cutting edges and a conchoidal surface. Flint occurs in nodules in chalk, not infrequently the nodules are chalcedonic. Hornstone differs from flint in being more brittle, impure hornstone. Limestones containing hornstone or chert are often called cherty limestone.

Silicified Wood. Petrified wood often consists of quartz, quartz having taken the place of the original wood. In some specimens the wood is converted into chalcedony and agate of various colors, having great beauty when polished.

Jaspery Varieties.

Jasper. A dull opaque red, yellow, or brownish siliceous rock. It also occurs of green and other shades.

Bloodstone or Heliotrope. Deep green, slightly translucent, containing spots of red, which have some resemblance to drops of blood. Contains a few per cent of clay and iron oxide mechanically combined with the silica. The red spots are colored by iron.

Lydian stone, Touchstons, Bassanite. Velvet black and opaque and used on account of its hardness and black color for trying the purity of precious metals; this is done by comparing the color of the mark left on it with that of an alloy of known character.

Opal. $SiO_2 + nH_2O$ (1% to 20% H_2O).

Compact and amorphous, texture colloid; also in reniform and stalactite shapes; also earthy. Color white, yellow, red, brown, green, blue, and gray. The finest varieties exhibit from within, when turned in the hand, a rich play of colors of delicate shades. Lustre waxy to subvitreous. Hardness 5.5 to 6.5. Specific gravity 1.9 to 2.3.

Precious opal. External color usually milky, but having a rich play of delicate tints; a gem of rare beauty.

Fire opal. An opal with lellow and bright hyacinth or fire-red reflections.

Common opal, Semi opal. Has the hardness of opal and its waxy or resinous luster, but no colored reflections from within, though sometimes a milky opalescence. The colors are white, gray, red, yellow, bluish, greenish, to dark grayish green. Translucent to nearly opaque.

Hyalite. Glassy, transparent; occurs in small concretions, occasionally stalactitic. Resembles somewhat transparent gum-arabic.

Wood opal. Gray brown, or black, having the structure of wood, being wood petrified by hydrated silica (or opal) instead of quartz.

Siliceous Sinter, Geyserite. A loose, porous, siliceous rock, grayish to white in color, deposited around geysers, as those of Iceland and Yellowstone Park, in cellular or compact masses, sometimes in stalactitic or cauliflower like shapes.

Tripolite. Diatomaceous or Infusorial Earth. A white or grayish-white earth, massive, laminated or slaty, made mainly of siliceous secretions of microscopic plants, called diatoms. Forms beds of considerable extent and often occurs beneath peat (because diatoms

lived in the waters of the shallow pond before it became a dying marsh.)

Quartz crystallizes in the rhombohedral division of the hexagonal system. When the crystal form develops it often consists of an hexagonal prism terminated by two rhombohedrons or sometimes only of double six sided pyramids made up of two rhombohedrons. Usually it occurs in the massive form with no crystal faces developed. These occurrences vary in their texture from coarse to fine grained or even to crypto crystalline, as in the case of the chalcedonic and jaspery varieties. Quartz does not tend to break along any well defined planes, in other words it has no cleavage, but breaks with equal readiness in any direction. It usually breaks with a more or less rounded or curved surface, and is therefore said to have conchoidal fracture. Its hardness according to Moh's scale is 7, which makes it a comparatively hard mineral. In specific gravity it varies from 2.653 to 2.654. In thin sections quartz is colorless, but often shows inclusions of various kinds which serve as pigments and give a color to thick slabs and masses of the mineral. At times, therefore, it may be yellow, red, brown, green, blue, or even black in color. It has a glassy or vitreous lustre.

According to Day and Shepherd quartz fuses at a temperature of about 1,600° C., or 2,912° F. When finely ground quartz is heated with tungstate of soda it remains unchanged until a temperature of about 870° C is reached. At temperatures above this it is gradually converted into tridymite. Tridymite occurs in nature as a mineral in certain volcanic lavas, especially the more siliceous and feldspathic kinds, as small aggregations in the massive rock, or also frequently in cavities associated with quartz or opal massive rock, or also frequently in cavities associated with quartz or opal and feldspar. It has also been found in meteorites. Tridymite is stable at all temperatures from 870°±10C up to 1,470°±10C, where the inversion to a third form known as Cristobalite takes place. From 1,470°C on, no further change occurs up to the melting point.[11]

Quartz is unattacked by acids other than hydrofluoric, and is only slightly attacked by solutions of the fixed caustic alkalies. This resistance to the attack of the ordinary acids explains the general absence of alternations in the quartz crystals of rocks, except where they have been subjected to profound alteration or metamorphism. Ordinary processes of alteration and decomposition do not affect quartz. It appears fresh and unaltered when other minerals have been decomposed.

Attention has already been called to the fact that quartz is often colored by the presence of inclusions. These may be divided into

11. The various forms of silica and their mutual relations. Clarence N. Fenner. Journal of the Washington Academy of Sciences. December 4, 1912. (Vol. 2.)

gaseous, liquid, and solid substances, the latter usually consisting of minerals of various kinds. The gas and liquid inclusions usually occupy irregular shaped cavities in the quartz, although sometimes they have the form of the enclosing mineral. The liquid in most cases is water, but liquid carbon dioxide may also be present. Gaseous bubbles, sometimes movable, often accompany the liquid. Cubes of some colorless mineral, possibly sodium chloride, are also found at times in these cavities. At other times a carbide is present in the liquid. This causes the fetid oder of certain samples of quartz when struck a sharp blow. The milky white color developed in certain quartzes is generally due to the reflection of light from these inclusions of gas and liquid.

Among the solid inclusions found in quartz are a considerable number of minerals. One of the most common of these is rutile, a titanium oxide, which often occurs in quartz as extremely thin microscopic needles. Minute crystals of apatite and plates of ilmenite abound in blue quartzes found in certain granites and porphyries. Other minerals occasionally found in quartz as inclusions are needles of tourmaline, epidote, actinolite, tremolite, and chlorite. These are the most common mineral inclusions, but others have also been found in certain quartzes. They are often arranged along lines, curved surfaces, or sometimes parallel to the crystal faces of the quartz.

Quartz is one of the most abundant minerals found in nature. It is an essential constituent of many igneous rocks, among the more important of which may be enumerated rhyolite, granite, dacite, quartz diorite, and granite pegmatite. In such sedimentary rocks as sandstone and conglomerate and the corresponding loose materials, sand and gravel, from which these are derived, it is usually the chief, and often nearly the only constituent present. In many of the metamorphic rocks such as the quartzites, gneisses and mica schists it is also important constituent. In addition to the above occurrences it is a very important vein forming mineral, frequently filling fissures and other cavities and crevices in the rocks. Considerable quantities are also deposited at times by hot springs and geysers. F. W. Clarke estimates that quartz forms about 12% of the entire lithosphere.

From its widespread distribution in nature it will be readily recognized that the mineral quartz must form under a great many different conditions. Where it occurs as an important constituent of certain types of igneous rocks it has crystallized directly from the molten condition. It is usually one of the last minerals to separate out when crystallization takes place in a cooling lava or magma. Quartz occuring as a vein filling in fissures and other crevices in the earth's crust has crystallized out from water solutions. These solutions may have been at high temperatures at the time the crystallization

took place or they may have been at ordinary temperatures, the mineral being found in both types of veins. Quartz therefore forms in nature either as a direct crystallization product from molten magmas or by precipitation from water solutions.

From the standpoint of the glass manufacturer only a few of the many occurrences of quartz are of interest as a possible source of silica for his use. At the present time pure quartz sands made up entirely of little quartz grains varying in size from 0.1 to 0.4 millimeters in diameter furnish practically the only source of silica for the glass industry.

As has been stated before, quartz is an important constituent of many of the rocks which make up the lithosphere or solid portion of the earth. Rocks are simply aggregates of one or more minerals. They can be divided into three large groups, namely:—igneous, sedimentary and metamorphic. Igneous rocks are those which have been formed by consolidation direct from the molten state, sedimentary are those which have been formed by the accumulation and consolidation of materials derived from the mechanical disintegration and chemical decomposition of previously existing rocks of any one of the above types, by the various agents of weathering, and metamorphic rocks are those which, originally igneous or sedimentary, have been altered in texture, structure or composition through any one or more of the various geologic agencies. Rocks are found in all three of these groups which have quartz as an essential constituent. Among igneous rocks such types as rhyolite, granite, dacite, and quartz diorite may be mentioned, in the case of sedimentary rocks, sandstones and conglomerates, and among metamorphic rocks, quartzites, mica schists and gneisses.

For the purpose of glass manufacture, however, it is necessary that quartz be not only an essential constituent of the rock but it must be practically the only constituent present. This type of rock is found only in the case of certain sandstones among the sedimentary rocks. Sand deposits and sandstones are found in nature that analize over 99% SiO_2. It is therefore in the occurance and origin of this type of sedimentary rock that the glass manufacturer is particularly intersted.

As has already been stated, sedimentary rocks are derived from materials produced from the mechanical disintegration and chemical decomposition of previously existing rocks on the earth's surface which have been exposed to the action of the various atmospheric agents, such as the gases present in the air and rain, frost, and changes of temperature. The alteration which takes place when rocks are thus exposed is known as weathering. Under ordinary conditions it involves both mechanical and chemical changes in the rocks exposed at the earth's surface.

Temperature changes and frost are the most active in producing mechanical disintegration of the rocks which crop out at the earth's surface. Where naked rocks are exposed to the direct rays of the sun during the day the outer layers become heated and expand. As rocks are poor conductors of heat only a comparatively thin shell is affected. At night these same rocks are cooled from the surface inward and contract, the outermost portion cooling off first, while a little further down the rock is still heated. This causes stresses to be set up in the rock, which after a time are sufficient to cause it to exfoliate or split off from the surface. Crevices and fissures in the rocks are also gradually widened by these stresses.

Most rocks are made up of aggregates of more than one mineral. Each of these minerals will have a different coefficient of expansion. When, therefore, the temperature rises the minerals expand and crow'd against each other, and when the temperature drops they contract and draw further apart. The stresses thus produced by the unequal expansion and contraction of the minerals making up a rock will cause the formation of small cracks, by which water will get access to the rock and set up chemical action, or in which the roots of plants will get a hold and further disintegrate it.

Most rocks are traversed by fractures, cracks and joints of various kinds, running in different directions. They are also more or less porous. Water gets into these openings and, if the temperature drops sufficiently, it freezes. In doing so it expands about 1-10 of its original volume and exerts a pressure of about 150 tons to the square foot. When the entire opening is full of water at the time the freezing occurs a tremendous force will thus be exerted on the rock, which tends to disrupt it. In this manner rocks are broken down into smaller and smaller fragments at the earth's surface.

The above examples illustrate some of the more important ways in which rocks are mechanically disintegrated. These do not involve changes in the chemical composition of the rock.

Moisture, especially when it condenses in the form of rain, is the most active agent of the atmosphere in producing chemical decomposition. A part of the rain which falls on the earth's surface evaporates again and passes into the atmosphere, a part runs off the surface and finds its way into streams and rivers, while a third portion soaks into the ground. It is this portion which is the active agent in producing chemical decomposition of the mineral constituents which make up the rocks.

Rain water always contains in solution varying amounts of the gases present in the atmosphere, among which oxygen and carbon dioxide are the most active chemically. As has already been stated practically all rock masses are traversed by fractures and cracks of varying size and the rocks themselves are more or less porous. The water which soaks into the ground traverses these crevices in

its downward course and thus comes in contact with the minerals of the rock, which it attacks.

The most important chemical reactions which result are hydra-tion, oxidation, carbonation, and solution. Hydration consists in the absorption of water which results in the production of hydrous minerals. Oxidation consists in the conversion of compounds of a lower state of oxidation to ones of a higher state. Carbonation consists in the union of carbon dioxide with bases to form car-bonates. Carbon dioxide replaces silica in silicates. Many of the compounds formed by the above reactions are more or less soluble in water and are, therefore, dissolved by the ground water as it perco-lates through the rocks and are carried away in solution.

As a result of these processes of weathering, involving mechanical disintegration and chemical decomposition of the rocks exposed at the earth's surface, a loose mantle of material accumulates when-ever the various agents of transportation, such as wind and water, are not sufficiently active to remove it as fast as it forms. Soil is the name which is commonly given to this mantle. It consists largely of unaltered, or only partially altered, fragments of the original rock, in addition to the various secondary minerals derived from the alteration of the original minerals which made up the rock from which it is derived. Certain of the rock minerals are attacked readily and, therefore, disappear in the soil, being repre-sented only by alteration products derived from them. The mineral orthoclase, which is one of the important minerals in certain igneous rocks, may be taken as an example to show how the agents of the atmosphere will attack and decompose a mineral. The reaction is as follows:

$$2KAlSi_3O_8 + 2H_2O + CO_2 = H_4Al_2Si_2O_9 + 4SiO_2 + K_2CO_3$$

Orthoclase+water+carbon=kaolin +silica+potassium

dioxide carbonate
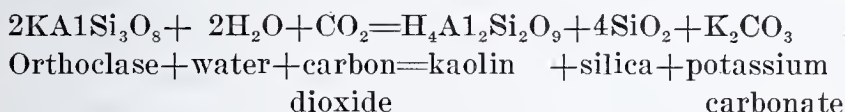
In the above case the kaolin will remain behind in the soil as a soft clayey mass. The silica when first liberated is a little more soluble, and may be carried away in part in solution, to be precipi-tated again at lower levels in the form of quartz. The potassium carbonate is readily soluable in water and goes into solution. Most of the other rock making minerals are attacked in a similar man-ner, some more and some less readily than orthoclase, the resulting products forming a soft, loose, clayey mass. The mineral quartz, on the other hand is very resistant and remains practically unaltered by the above agents of weathering. It is therefore left behind in its original condition in the residual mantle formed after the process of weathering has gone to completion.

The little grains of quartz of the original rock will, therefore, be distributed through the soft, loose clayey material derived from

the alteration of the other important rock making minerals. In order to get a quartz sand it is now necessary for one or more of the various agents of transportation present in nature to remove this weathered material from its original position and separate the quartz from the clayey material or soil in which it is imbedded.

Running water is one of the most important transporting agents found in nature. A part of the rain which falls on the earth runs over the surface, carrying portions of the soil with it. This runs off, collects to form streams, which unite to make rivers. Weathered material is thus washed into the streams and is carried along by them, either in mechanical suspension or rolled along the bottom. The amount of material transported depends upon the velocity and volume of the stream. Whenever the velocity is checked, deposition occurs. The coarser material is deposited first, likewise the heavier. A separation according to size and specific gravity therefore results, and thus streams act as sorting as well as transporting agents.

The coarsest material, known as gravel, consists largely of more or less rounded fragments of unaltered, or partially altered, rock which have been washed into the streams. The next material in size, is called sand. This is made up of grains which approximate in size those of the minerals which made up the original rock. Therefore sand carried by streams consists largely of quartz grains, for, as has been pointed out, the other rock making minerals tend for the most part to be decomposed by the process of weathering into soft, readily pulverized, secondary minerals, which give rise to the fine silt and mud carried by the streams. The relative percentage of quartz present depends largely on the degree of completion which the process of weathering has attained before the material was washed into the streams. Quartz is also harder than the other common rock forming minerals and does not suffer so much from wear, due to attrition of colliding grains during transportation as do the other minerals, unaltered fragments of which may be present in the sand, these latter being gradually worn to a fine silt. The finest material, the silt and mud, carried by streams in mechanical suspension consists largely of secondary minerals, such as kaolinite, and other hydrated silicates of aluminum, limonite, etc. This is the last material to settle out when the velocity of the stream is checked.

Streams deposit the material which they carry mechanically at various places along their courses and at their mouths, where they enter bodies of standing water. Deposition occurs wherever there is a decrease in velocity. When streams flow from mountainous regions onto plains, large deposits, in the shape of alluvial fans and cones, are often built up on the plain at the base of the mountains. A number of these fans may coalesce to form a large alluvial plain. As a rule sorting is very imperfect in these deposits and sand of

PLATE II.

Fig. 1.   Sand dunes along dry channel of Rio Puerco, south of Adamana, **Arizona.**

Fig. 2.   Cross-bedding in wind blown sand, Rio Puerco valley, Adamana, Arizona.

sufficient purity for glass making is rarely found in them. At times, however, especially if the stream is deriving its material from an already fairly pure quartz sandstone formed during some previous geologic period, fairly pure quartz sands may accumulate under those conditions. The Pottsville sandstone of western Pennsylvania, formed during the early part of the Pennsylvania period, represents such a deposit.

Streams also deposit considerable amounts of material at various places along their courses, especially the lower portions, so that sand deposits are often found along the flood plains of rivers. At times these deposits are of sufficient purity to be used in the manufacture of glass. Such deposits were formerly worked along the Monongahela river in the vicinity of Belle Vernon, Pa.

Finally, all material still carried mechanically by the stream when it enters a body of standing water is deposited at or near the mouth of the stream. Here sorting is usually more perfect. The coarse material, or gravel, come to rest first, then the sand, and finally the mud and silt. Where the stream enters a large lake or the ocean wave action further assists in the sorting, by washing out the finer material from the sand. In the case of the ocean the waves, undertow, rising and falling tides, and shore currents due to waves striking the shore at oblique angles, all assist in this sorting, so that at times deposits of nearly pure quartz sand result. The attrition of the colliding grains also gradually wears the softer ones down to a fine powder which is washed away, until eventually only the harder ones like quartz remain behind. If the coast is a gradually subsiding one such deposits may reach a thickness of several hundred feet. The Oriskany sandstone of central Pennsylvania represents a deposit of this character formed during the early part of the Devonian period. Sands running over 99% SiO_2 are reported as accumulating at the present time along the gulf coast of Florida in the vicinity of Pensacola and Tarpon Springs.[12]

Wind is another transporting and sorting agency which at times in conjunction with running water, or at times alone, is instrumental in the accumulation of extremely pure quartz sands. The ultimate source of the material transported by the winds is also derived largely from the products of atmospheric decay, which may or may not have been transported by water previous to the time it was taken up by the wind. Dry sand is readily blown about by the wind. Where the wind is in some prevailing direction it carries the sand along with it, heaping it up in the form of dunes, which are hills of sand similar to the drifts formed in the case of snow which is being borne along by the wind. Plate II shows the appearance of such dunes occuring along the valley of the Rio Puerco at Adamana, Arizona.

12. United States Geological Survey. Mineral Resources of the United States, 1911, Part 2, pp 585-608.

The large grains of sand are carried along close to the surface, while the finer particles are carried to considerable heights by the wind. In this way the fine material is separated from the coarse.

The unequal hardness of different minerals plays a much more important part in the separation which occurs in wind blown sands than it does in river sands. The grains do not have a cushion of water to protect them from abrasion by one another as they are blown along by the winds. As a result the softer ones gradually become reduced to dust, which is blown away by the wind, while the harder ones remain behind. Quartz is among the hardest of the common minerals present in sand so that the more handling the sand receives by the wind the greater becomes the percentage of quartz present, until finally a practically pure quartz sand, made up of well rounded grains results. The rounding of the grains may often be used as a criterion to distinguish wind blown sands from water laid sands, as the latter are usually more or less angular, because grains the size of ordinary sand are protected from abrasion by the cushion of water around them. Victor Ziegler carried on some experiments which led him to the conclusion that quartz grains less than 0.75 milimeters in diameter could not be rounded under water, but if rounded they were wind worn.[13] Wind worn grains also loose their glassy character and become dimmed by attrition, so that the surface of the grains assume the appearance of ground glass.

Wind blown sands frequently occur along low lying sea-coasts, along river flood plains in arid and semi-arid regions, and in desert regions. The St. Peter sandstone, which is quarried so extensively for glass sand around St. Louis, Missouri and at Ottawa, Illinois, is an example of a wind blown sand, deposited on a low-lying plain, occupying the upper Mississippi valley region during the early part of the Ordovician period.

Sands which are deposited over a gradually subsiding area may become buried to very considerable depths by later sediments laid down on top of them. If a little clayey material was deposited with the sand the pressure may be sufficient to consolidate the mass into a rock. At other times the sand is bound together by mineral matter deposited between the grains from water solutions percolating through the sand. The most common cementing agents are silica (SiO_2), calcite ($CaCO_3$), dolomite ($CaCO_3.MgCO_3$), and iron oxides, usually the hydrated ferric oxide, known as limonite, but at times also the simple ferric oxide, hematite. Where iron oxide forms the bond the sandstone is rendered unfit for glass making.

Deposits of sand and resulting sandstones formed as outlined above may, during a later stage in the geologic history of a region, become

13. Journal of Geology, Volume XIX, pp. 645-654.
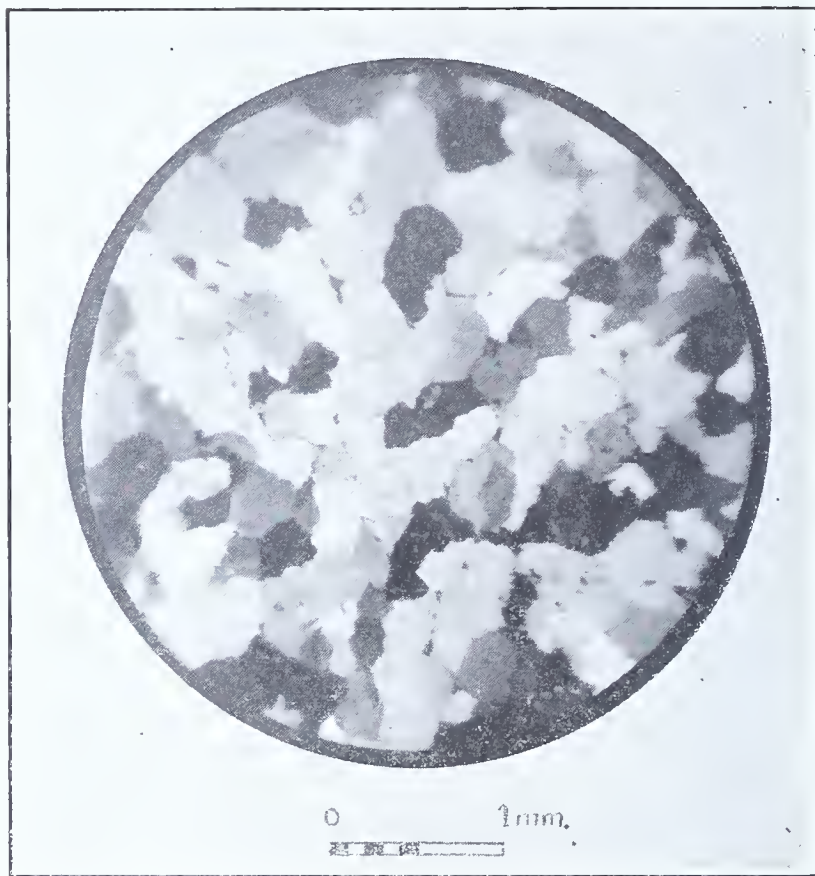
PLATE III.
Photo micrograph of quartzite from Tuscarowa formation,
Jacks Mountain, Mapleton, Pa. Crossed nicols.

elevated vertically to varying heights above sea level. Erosion may remove the overlying sediments and expose the sandstone again at the surface. At times also in its geologic history a region which has undergone gradual subsidence over a considerable interval of time, with the deposition of a thick series of sedimentary rocks, may become subject to lateral compression produced by the gradual shrinkage of the earth. The horizontal layers of the rock are then thrown into a series of arches and troughs, called anticlines and synclines respectively, and the beds thus become tilted at various angles. The great pressure brought about by this lateral compression, acting in conjunction with a somewhat higher temperature due to the burial of the rocks to a considerable depth beneath the earth's surface, often causes considerable recrystallization to occur in the rocks, so that a sandstone becomes converted into an extremely hard and tough quartzite. Small amounts of water present between the grains of sand also assist in this recrystallization. During this process the original grains become entirely obliterated and a clear quartz mosaic results. Plate III is a photograph of a thin section of quartzite, used for silica brick, from Mapleton, Pennsylvania, as it appears under a petrographic microscope with cross-nicols.

When the sandstone is again elevated above sea level by movements underneath the earth's surface and exposed to weathering by the process of erosion, the tendency again is to convert it into loose sand. The rate at which the agents of weathering disintegrate it depends largely upon the bond. A sandstone with calcite as a bond, for example, disintegrates to a loose sand much more readily than one with a silica, clay material, or iron oxide bond, because calcite is comparatively readily soluble in water containing carbon dioxide. At and near the surface, therefore, sandstone often become quite friable, due to weathering, and can be readily crushed to sand for glass making purposes, provided the stone is sufficiently free from deleterious constituents.

An ideal sand or sandstone for glass making would consist entirely of quartz grains. In as much as absolutely pure quartz sands or sandstones are not found in nature, however, it becomes necessary to determine what impurities are permissable and to what amounts they may occur in a sand and still not render it unfit for the manufacture of glass. This depends largely upon the kind of glass for which the sand is to be used. Optical and high grade lead flint glass require a much purer sand than ordinary or bottle glass. The size and shape of the sand grains are factors which must be considered, but these are not nearly so important as the chemical composition of the sand.

When a quantitative analysis is made of a glass sand there are usually found in addition to the silica small amounts of Al_2O_3, Fe_2O_3, MgO, CaO, H_2O, and TiO_2, also occasionally a little Na_2O, K_2O, and organic matter. This is due to the fact that there are usually present, even in the purest sands, minute amounts of other minerals, such as mica, especially muscovite and sericite; feldspar, including orthoclase, microcline, and plagioclase; hornblende; titanite; magnetite; ilmenite; sphene; rutile; zircon; apatite; kaolinite, or other hydrated aluminum silicates; limonite, hematite, calcite, dolomite, chlorite, etc.

Alumina occurs in glass sands usually either in the form of feldspar (either orthoclase ($KAlSi_3O_8$), or plagioclase ($mNaAlSi_3O_8$-$+nCaAl_2Si_2O_8$)), muscovite ($H_2(K,Na)Al_3(SiO_4)_3$), or kaolinite ($H_4Al_2Si_2O_9$). The latter is the most frequent occurrence. The small quantities of clayey material associated with most sand deposits consist largely of this or some very similar hydrated aluminum silicate. Kaolinite and muscovite may be removed, at least in large part, by washing the sand. Grains of unaltered feldspar, on the other hand, cannot be very well separated from quartz grains in this manner.

There is still some difference of opinion among manufacturers as regards the effect on the glass of alumina in sand. Some regard it as a harmful constituent, while others do not. In fact there is considerable evidence to show that in the case of certain glasses it is even advantageous to have it present in small quantities.

Dralle cites a number of examples and gives the results of experiments which indicate that alumina in high lime glasses tends to reduce their tendency to devitrify. Hovestadt also cites an example which occurred in actual practice. This was a thermometer glass made in the Thuringian Forest of Germany which would stand repeated melting, blowing, and fusing without change, while ordinary glass, such as is used for windows, became rough and dull of surface even on short exposure to the flame. Upon inquiry it was found that the Thurningian glass owed its special qualities to a certain sand used in its manufacture, which was only found in the neighborhood of the village of Martinsroda. Upon analysis it was found that this sand contained 3.66% alumina. Experiments with pure quartz sands to which this amount of alumina was added gave exactly the same results as the Martinsroda sand, showing that the special properties imparted to the Thuringian glass by the Martinsroda sand were due to its alumina content. Schott suggests that the presence of the alumina hinders the volatilization of the alkalies at the surface of the glass, but it is also possible that the dulling of the glass is due to incipient crystallization or devitrification and that the alimina tends to prevent this. Frink[14] has also observed

14. Transactions American Ceramic Society, Vol. II, 1909, pp. 99-102.

that when alumina exists to the extent of 3 or 4 per cent in a finished glass the glass is not nearly so susceptible to the carbonizing or reducing action of the fire, or to the formation of cords and strings, or production of a laminated condition, whether soda or salt cake be used for supplying the soda content. Dralle also states and gives examples indicating that alumina has a very favorable influence in the durability of glass by decreasing its solubility in water, weak acids, etc. Frink[15] has found the same thing to hold true of a large number of bottle glasses of known composition.

Alumina has also certain favorable influences on the physical properties of glass. Frink[16] states that from his observations he is lead to conclude that alumina has the tendency to increase the surface tension when the surface is rapidly chilled. This is a valuable property in the manufacture of glass in molds, for when a glass containing 3 to 5 per cent of alumina has been gathered or ladled from a mass of molten glass at a temperature of about 1150° C, its surface immediately becomes lower in temperature, dropping to about 825° C, and the skin or overlying stratum will become very tenaceous. When a glass of this character is placed in the molds and is pressed or blown it has less tendency to take on the various small imperfections in the mold, but at the same time it will be sufficiently plastic to be forced into any shape. Alumina is an especially valuable ingredient in the manufacture of bottle glass because it reduces the coefficient of expansion and increases the tenacity of the glass. It also facilitates annealing, because a bottle will stand much more severe usage without breaking and the glass does not require annealing to be conducted in as careful a manner as in the case of other glass. An alumina glass is also somewhat harder and a little more brilliant than ordinary glass.

One of the disadvantageous properties of alumina is that it decreased the fusibility of the glass. Likewise it increases the viscosity when present in amounts exceeding 3%. Also glass containing alumina does not mix well with other glass to form a perfectly homogeneous mass, free from cords. Care must, therefore, be exercised in using such glass as cullet.

The above observations leads one to conclude that for all ordinary varieties of glass the small amount of alumina usually present in glass sands has no injurious influence on the glass, and if anything is beneficial. Frink[17] cites an interesting case where a sand containing 7.26% Al_2O_3 and 0.31% Fe_2O_3 gave a class of superior physical properties to that of sand containing but 0.68% of Al_2O_3 and Fe_2O_3 combined. The glass made from the first sand contained 70.51% SiO_2, 5.98% Al_2O_3, 0.23% Fe_2O_3, 9.57% CaO, 0.81% MgO and 12.87%

15. Transactions American Ceramic Society, Vol. 15, 1913, pp. 706-727.
16. Transactions American Ceramic Society, Vol. 11, 1909, pp. 99-102.
17. Transactions American Ceramic Society, Vol. 11, 1909, pp. 296-319.

Na_2O, while that from the second or purer sand contained 72.01% SiO_2, 1.81% Al_2O_3 and Fe_2O_3 combined, 12.48% CaO, 0.41% MgO and 13.21% Na_2O. The former showed an increased resistance to tension 8.3% in modulus of rupture, and had a higher lustre. It had a remarkable power of resistance towards alkalies and was not attacked as readily by acids. It also annealed readily, but was somewhat more susceptible to changes in temperature and had a considerable higher viscosity at given temperatures.

Iron occurs in glass sands both in the ferrous and ferric conditions. It is usually present as limonite ($Fe_2(OH)6Fe_2O_3$), hematite (Fe_2O_3), or magnetite (Fe_2O_4), but sometimes such minerals as ilmenite, hornblende and chlorite, present in some quantities in the sand, will also contribute towards its iron content. Limonite usually occurs intimately mixed with the kaolinite or other hydrated aluminum silicates, forming the small amount of clayey material associated with the sand, or thin films of limonite sometimes coat the little sand grains or fill minute crevices in the grains due to fracturing. Where the iron is present as limonite mixed with clay it may be largely removed by washing. Sands that are cream colored, yellowish brown or brown, contain limonite, the shade of color depending upon the amount of limonite present. Hematite colors a sand reddish brown. The color of the sand cannot always be taken as a criterion of the amount of iron present, however, as a light colored or nearly white sand may contain sufficient magnetite or ilmenite to make the iron content higher than that of a yellowish brown sand containing the iron in the form of limonite. When iron is present largely as magnetite or ilmenite it may be removed by magnetic separation.

Iron is the most detrimental impurity found in glass sands on account of its coloring effect on the glass. Ferrous iron gives the glass a bluish-green tint. Because nearly all glasses contain at least traces of iron, when glass is viewed through a thick section it always has a greenish cast. The color becomes more intense as the percentage of iron increases, so that ordinary bottle glass which contains a relatively high percentage of iron is often spoken of as green glass. Ferric iron, on the other hand, gives the glass a yellow tint, which is not nearly as noticeable. Certain decolorizing agents are often added to glass batches to neutralize these coloring effects of the iron, when it is present in only small quantities. These are described in a later paragraph.

The percentage of Fe_2O_3 which is permissable in the sand depends upon the kind of glass which is being manufactured. In the case of optical and the best grades of crystal or lead flint glass, if the other raw materials are very pure, the percentage of Fe_2O_3 in the sand may run as high as 0.02 according to Dralle. Rosenhain

places the upper limit as high as 0.05%. For plate glass Dralle gives the upper limit as 0.2% when the glass is viewed by transmitted light and 0.1% where it is used for mirrors. In the case of window glass, where thinner sheets are employed, and the glass is viewed by transmitted light, the iron content may run up to 0.5%, but should not exceed this figure. This is also the upper limit permissable for white bottles. For ordinary green and brown bottles sands running from 0.5% to 7.0% Fe_2O_3 are often used.

A rough insight into the amount of iron present in a sand may be obtained by taking 5 to 10 grams of the sand and warming with not too concentrated hydrochloric acid solution. This acid is then filtered off and treated either with a solution of potassium ferrocyanide or with potassium sulphocyanide. In the former case a blue precipitate will be obtained while with the latter the solution will be colored red if iron is present. The intensity of the color gives one an approximate idea as regards the amount of iron present in the sand. An exact determination, however, is not possible by this means because some of the iron may be present in the sand in such combinations with other elements as not to be soluble in hydrochloric acid. It is always necessary, therefore, in order to get the exact amount to make a regular quantitative analysis of the sand, either by fusing it with about four times its weight of equal amounts of sodium and potassium carbonate, or treating it with hydrofluoric acid to which a few drops of sulphuric acid have been added. The exact methods of procedure are given in standard books on inorganic quantitative analysis.

Magnesium and calcium oxides are frequently found to be present in minute quantities in glass sands, usually occuring in the sand as carbonates. In most sands used for glass making, however, the quantity is so small as to be negligible. They have no detrimental influence on the glass. Lime is a part of the composition of most of the ordinary glasses of commerce. Magnesia is much more apt to be introduced into the glass in appreciable quantities through the limestone employed as a raw material for lime than through the sand, and its effect on glass is, therefore, taken up under that head.

Where sand is used for the manufacture of the better grades of glass, such as optical, lead flint, lime flint and plate glass, it is usually dried artificially before it is introduced into the glass batch. For the cheaper grades of glass such as window and ordinary green bottle glass, wet sand is often employed. Where it is necessary to keep a close check on the composition of the batch dried sand alone should be used, as the percentage of moisture in wet sands is apt to vary greatly even in different parts of the same shipment of sand, making numerous determinations of moisture content, at frequent

intervals, necessary. Most of the water in sands is present as little films adhering to the grains. A little, however, may occur in chemical combination with other elements in the form of such minerals as kaolinite, limonite, chlorite, or muscovite.

A small amount of titanium oxide is found in practically all glass sands, whenever a determination of this element is made. This varies from a few hundredths to a few tenths of a per cent. Most of it is present in the form of little needles of rutile (TiO_2) which occur as inclusions in the quartz grains, especially in those which have been originally derived from igneous rocks. A little of it may also be present in the form of small grains of ilmenite ($(FeTi)_2O_3$, or titanite ($CaSiTiO_5$). The writer has not come across any data showing what effect titanium has on glass. The very small amounts usually present in glass sands undoubtedly are negligible as far as any influence on the properties of the glass are concerned.

Frink[18] has called attention to the fact that small grains of round pebbles, sometimes referred to as "ganister" by the glass men, when present in appreciable quantities produce small white stones in the glass because the temperature of the glass furnace is not sufficiently high to cause them to go into solution in the molten glass. According to Frink these pebbles usually consist of silicates of magnesium and lime, or lime and alumina. They are silicate minerals which were present in the original rock from which the sand was derived, which were not completely decomposed in the process of weathering and were not sorted out during the transportation and deposition of the sand. Such pebbles can be distinguished readily when the sand is examined under the microscope.

The size and shape of the grains is also a factor of some importance in determining the value of a glass sand, but usually this is only a matter of secondary consideration compared with the chemical composition of the sand. In regard to the most desirable size there is still considerable difference of opinion. Many hold that the majority of the grains should not pass a sieve having 120 meshes per linear inch. That is the majority of the grains should be over 0.136 millimeters in diameter. On the other hand the bulk of the sand should pass through a 30 mesh sieve, that is the grains should have a diameter of less than 0.64 millimeters. These sizes, however, are not adhered to by all glass manufacturers, and when the sand is otherwise nearly chemically pure variations are permissable. One glass manufacturer in Pennsylvania has been using sand pulverized so as to pass an 100 mesh sieve in the manufacture of the finer grades of his lead flint for cut glass articles, holding that the sand thus reacts more readily with the other raw materials

18. Glass Worker, Vol. 31, 1912, No. 9, pg. 2.

of the batch, as the quartz per unit of weight offers a relatively greater area to be acted upon than in the case of coarser grains. It is doubtful, however, whether enough is gained in this way to pay for the extra cost incurred by having the sand pulverized to this fineness. Thorough mixing of the sand with the rest of the materials of the batch also becomes more difficult when it is in such a finely divided state and when the sand is too fine there is apt to be a greater loss due to particles being carried away by the draught. This holds true especially in the case of tank furnaces. When the grains are uniformly larger than will pass a 30 mesh screen more time is required to have them react with the other materials of the batch and go into solution in the resulting molten glass. This necessarily decreases the output of the furnace.

The determination of the size of the grains of sand is made by passing a weighed amount of sand through a series of sieves arranged in regular order, with the coarsest mesh at the top. One hundred grams is a convenient amount to take as it obviates all calculations, the weight of sand remaining on each screen being the percentage by weight of the grains which have a diameter between that of the screen opening they are on and the next screen above. In making determinations of the size of sand grains the writer recommends the use of the Tyler Standard Screen Scale Sieves, manufactured by the W. S. Tyler Company of Cleveland, Ohio. This screen scale has as its base an opening of 0.0029 inches, or 0.074 millimeters, which is the opening of a 200 mesh, 0.0021 wire standard sieve as adopted by the United States Bureau of Standards. The openings increase in size from that upwards in the ratio of the square root of two, or 1.414. Unless some such standard is adopted it is very difficult to compare size determinations made by different individuals using different screens. The above screens were used in all size determinations made by the writer in connection with the preparation of this report.

It was formerly thought that the sand grains should be sharp and angular to give the best results. With the opening up of deposits of exceptionally pure quartz sands and sandstones in the Mississippi Valley region, around St. Louis, Missouri, Ottawa, Illinois, and in certain areas in Michigan, which are made up of well rounded grains, it has been found that these sands give excellent results in the case of ordinary varieties of glass, including lime flint, plate and window glass, and also lead flint for fine ware. The chemical purity of the glass used is the important factor. In this connection it may be said, however, that in the case of two sands of like purity and similar size of grains, the one in which the grains are sharp and angular is somewhat more desirable than the one made of well rounded grains, because for the same size grain in volume and weight the angular grain will have a greater area of surface exposed to the

action of the other ingredients of the glass batch when melting occurs, and will therefore react with them more readily.

Plates IV to XI show comparisons of shape of different sized grains in a sharp, angular sand, like that produced at the Keystone Works of the Pennsylvania Glass Sand Company, near Mapleton, Pennsylvania and a well rounded sand like that produced by the Wedron White Sand Company, of Ottawa, Illinois. The results of the size determinations of these two sands were as follows:

Percentage of Sands Passing Through Different Screens.

	Keystone No. 1.	Wedron No. 1.
Remaining on 20 mesh screen,	.07	.04
Remaining on 28 mesh screen, but through 20 mesh,	1.59	2.16
Remaining on 35 mesh screen, but through 28 mesh,	13.11	19.81
Remaining on 48 mesh screen, but through 35 mesh,	61.71	38.04
Remaining on 65 mesh screen, but through 48 mesh,	20.25	14.19
Remaining on 100 mesh screen, but through 65 mesh,	2.79	10.15
Remaining on 150 mesh screen, but through 100 mesh,	.16	6.63
Remaining on 200 mesh screen, but through 150 mesh,	.03	3.68
Remaining on 200 mesh,	.01	4.76
	99.72	99.49

Deposits of glass sand are found in nature in which the individual grains are not held together by a bond or cement of any kind, but occur simply as bodies of loose, unconsolidated material. Often, however, the individual grains are held together by a bond, forming what is called a sandstone. In the latter case it is necessary to crush the rock, so that the bond between the grains becomes severed and the rock crumbled to a loose sand. For making glass sand only such sandstones are desirable as break comparatively readily along the bond between the individual grains and not across the actual grains themselves. Very thoroughly cemented sandstones or quartzites are not desirable, as the process of crushing them to the desired size is an expensive one and much material of undesirable sizes results.

The method of preparing a glass sand from sandstone is taken up first. There are two methods in common practice. One is to crush, wash, dry, and screen the sand, while the other is simply to crush and screen. The former method is used in the preparation of the better grades of sand used in the manufacture of lead flint, lime flint, and plate glass, while the latter method is occasionally used for the cheaper grades of sand used in the manufacture of window glass and ordinary bottle glass.

By washing the sand the fine clayey material, consisting largely of kaolinite or some other hydrated aluminum silicate, with usually a little limonite mixed with it, is removed from the sand. This oper-

PLATE IV.
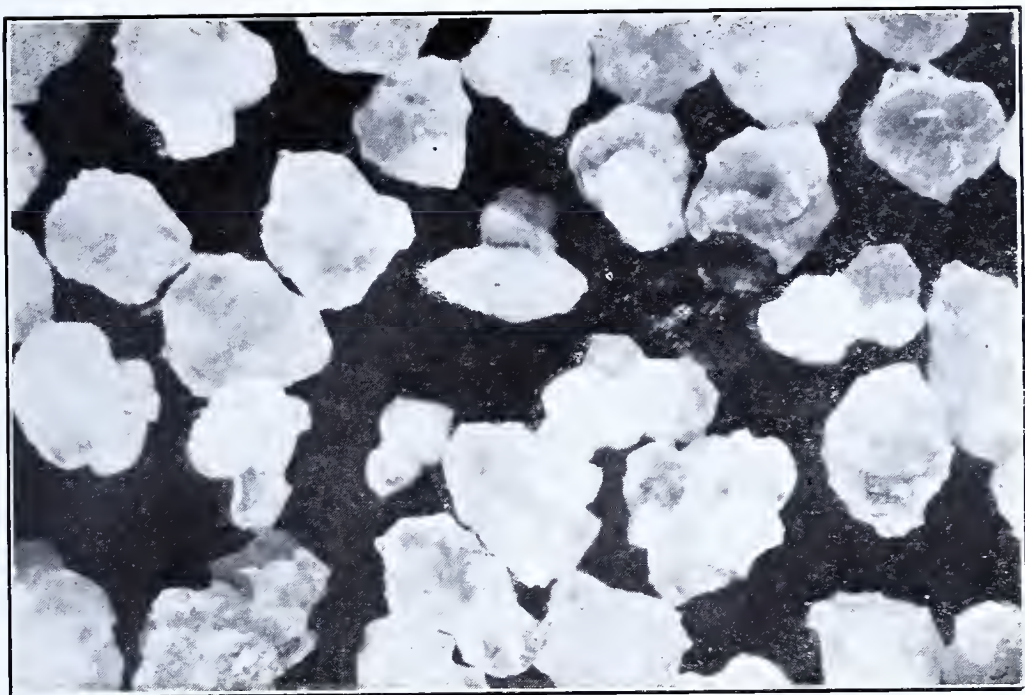
Fig. 1. Sand grains passed through 20 mesh sieve and caught on a 28 mesh sieve. Between 0.589 and 0.833 millimeters in diameter No. 1 sand. Keystone Works. Pennsylvania Glass Sand Co.. Mapleton. Pa.
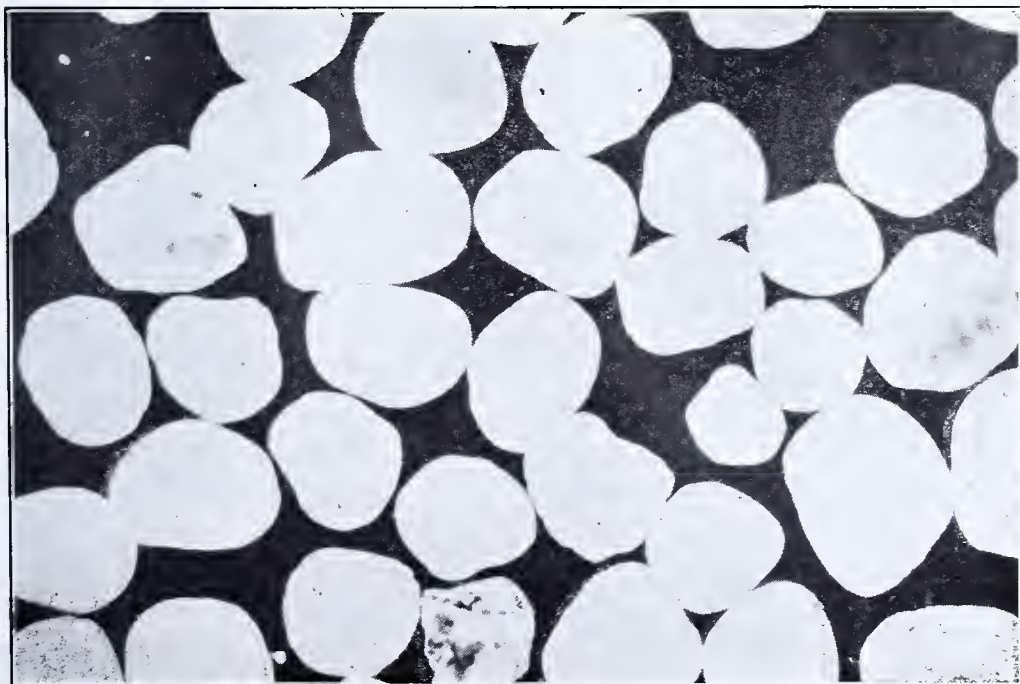
Fig. 2. Sand grains of same size. Wedron White Sand Co., Ottawa. Ill. No. 1 sand.

PLATE V.
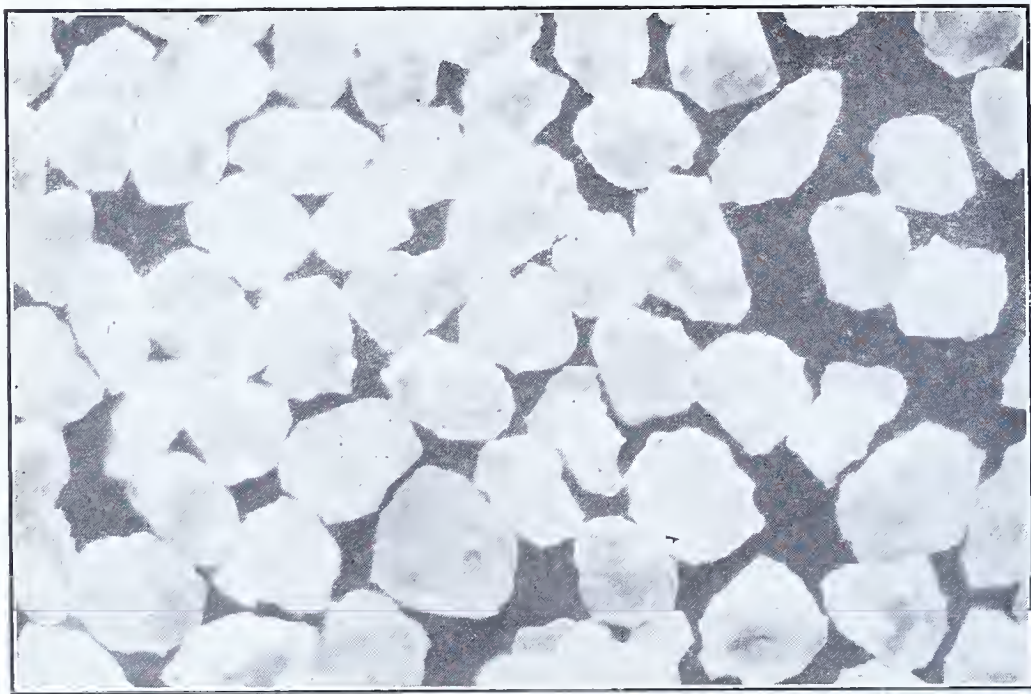
Fig. 1. Sand grains passed through a 28 mesh sieve and caught on a 34 mesh sieve. Between 0.417 and 0.589 millimeters in diameter. Keystone No. 1 sand.
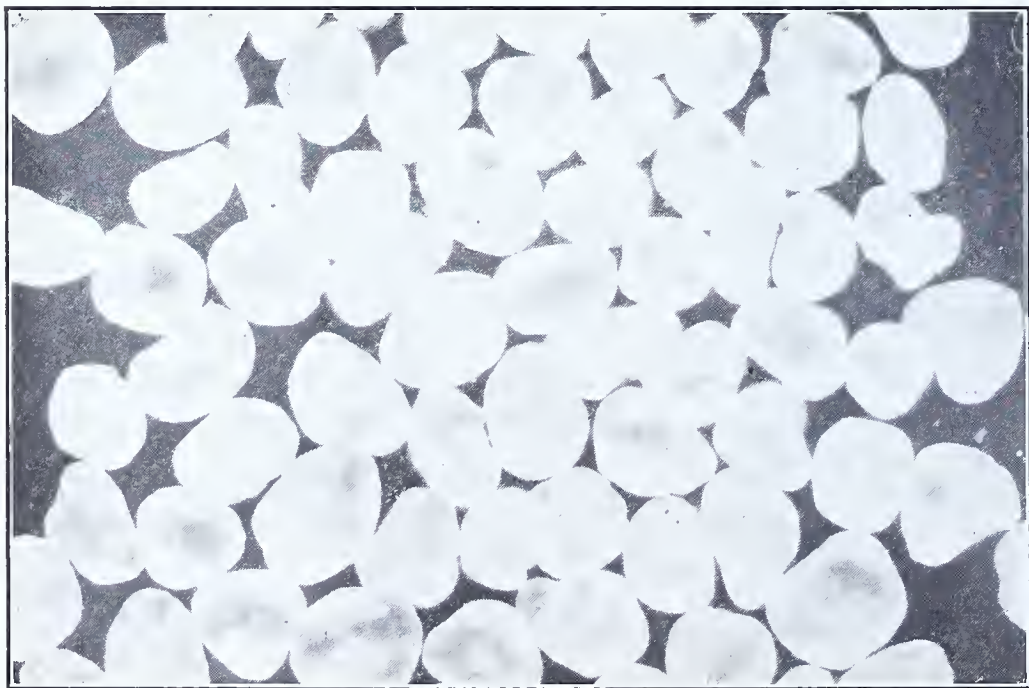
Fig. 2. Sand grains of same size, Wedron No. 1 sand.
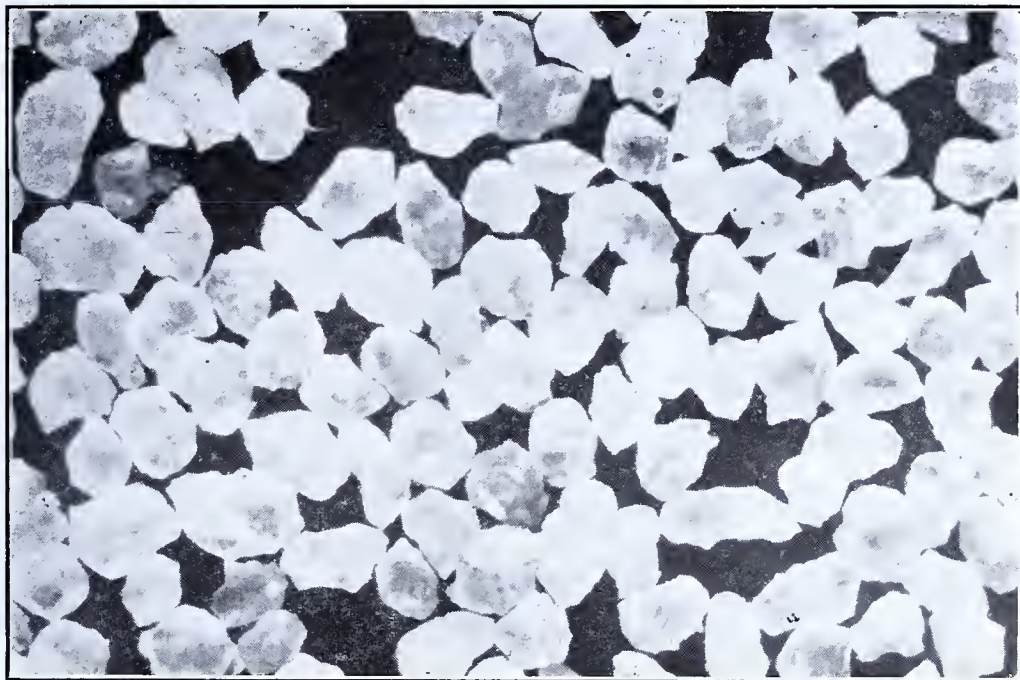
PLATE VI.

Fig. 1. Sand grains passed through a 35 mesh sieve and caught on a 48 mesh sieve. Between 0.295 and 0.417 millimeters diameter. Keystone No. 1 sand.
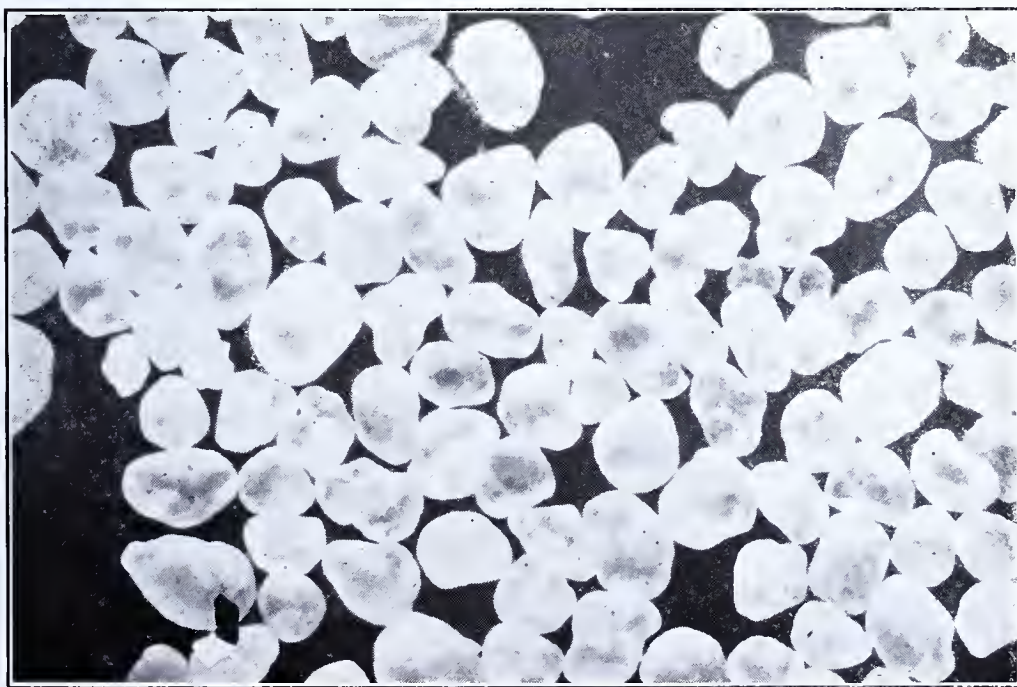
Fig. 2. Sand grains of same size, Wedron No. 1 sand.

PLATE VII.
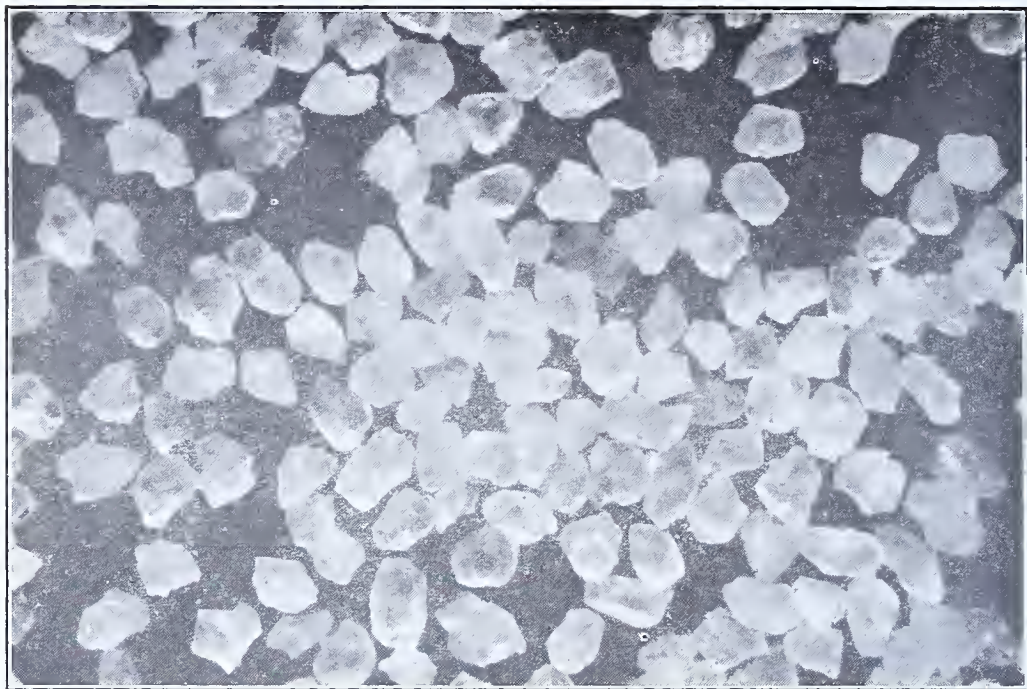
Fig. 1. Sand grains passed through a 48 mesh sieve and caught on a 65 mesh sieve. Between 0.208 and 0.295 millimeters in diameter. Keystone No. 1 sand.

Fig. 2. Sand grains of same size, Wedron No. 1 sand.

PLATE VIII.
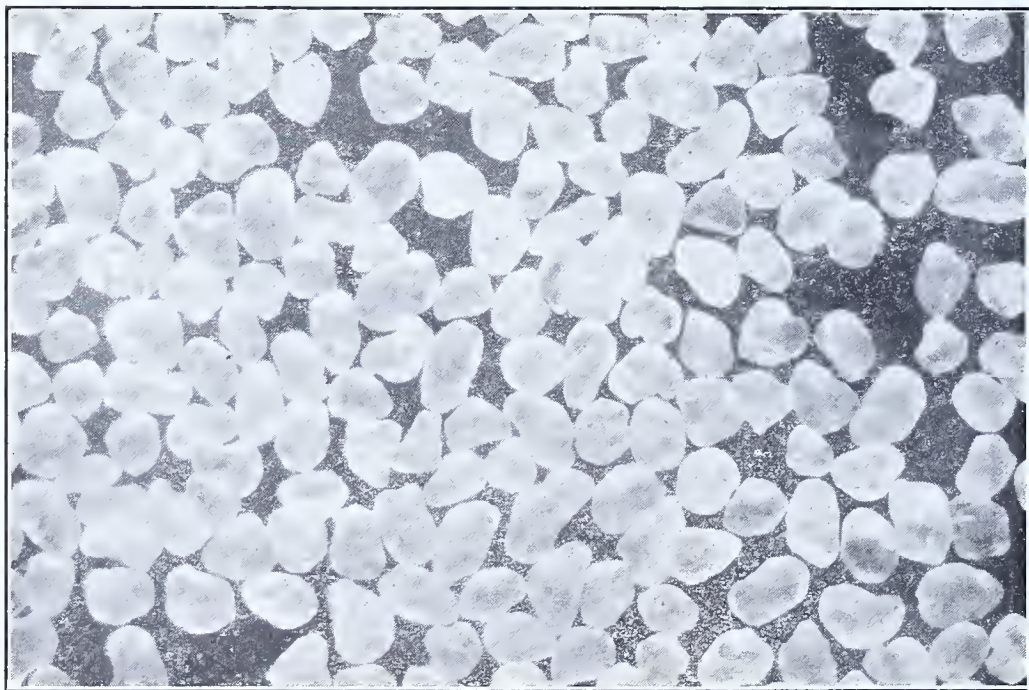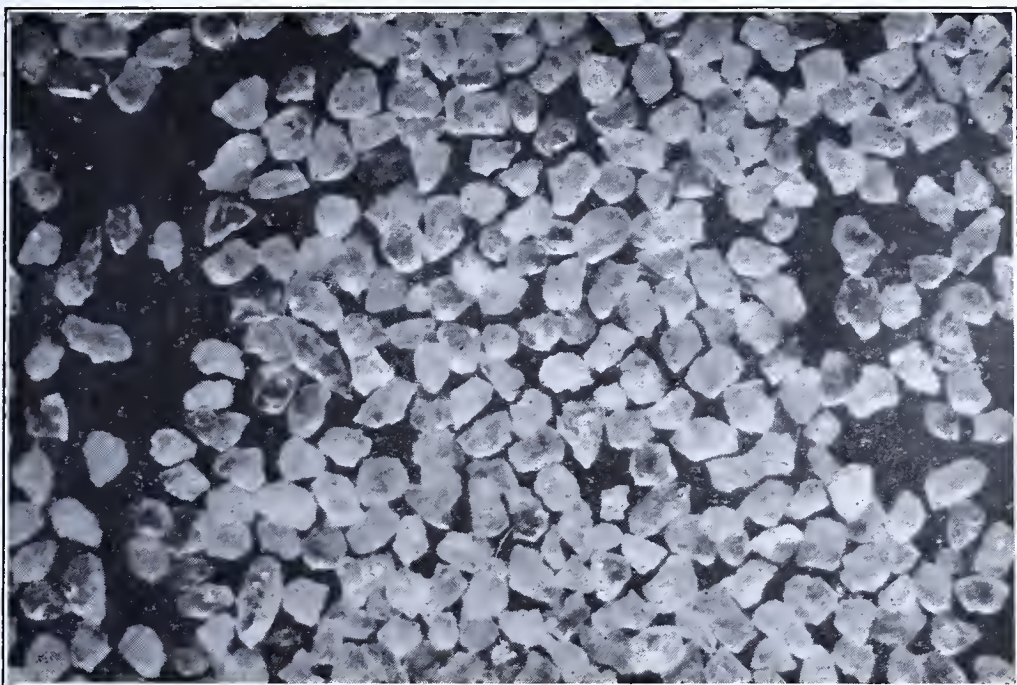
Fig. 1. Sand grains passed through a 65 mesh sieve and caught on a 100 mesh sieve. Between 0.147 and 0.208 millimeters in diameter. Keystone No. 1 sand.
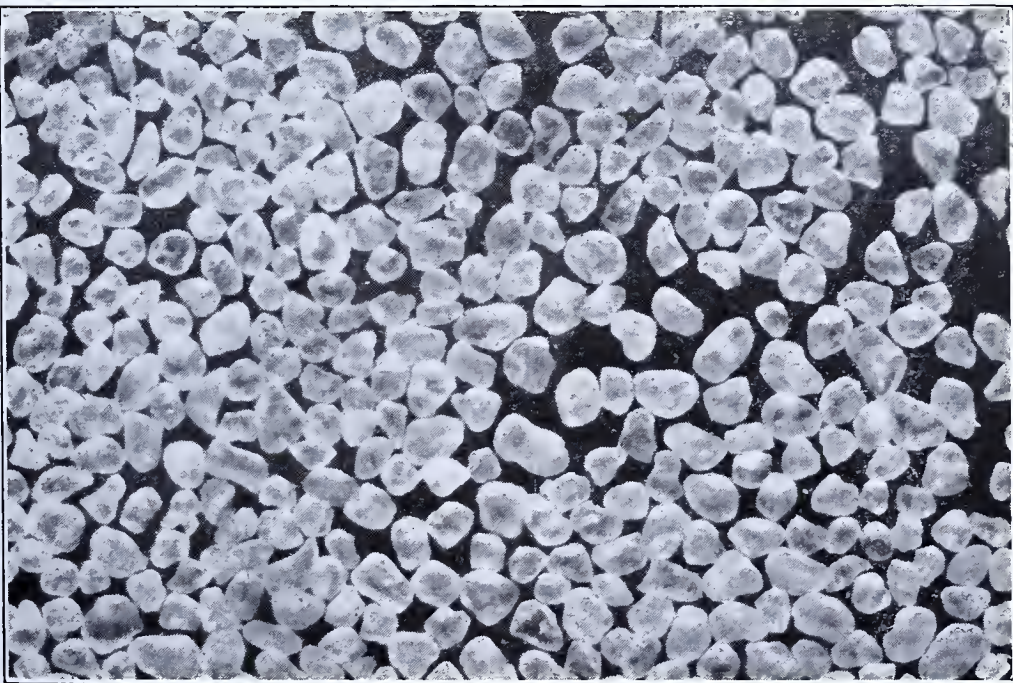
Fig. 2. Sand grains of same size, Wedron No. 1 sand.

PLATE IX.
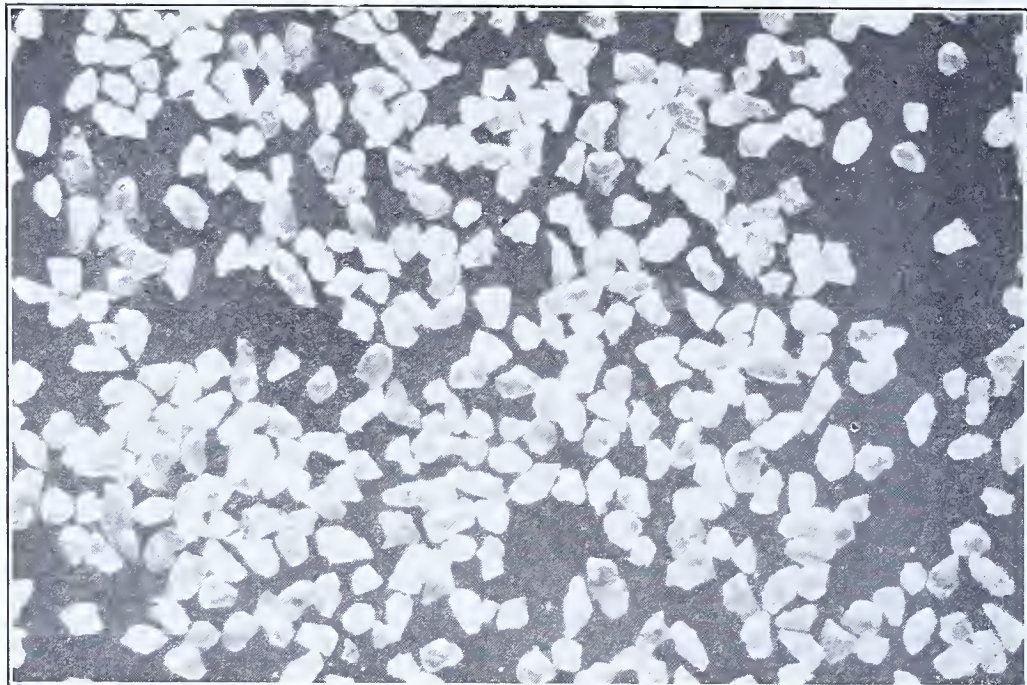
Fig. 1. Sand grains passed through a 100 mesh sieve and caught on a 150 mesh sieve. Between 0.104 and 0.147 millimeters in diameter. Keystone No. 1 sand.
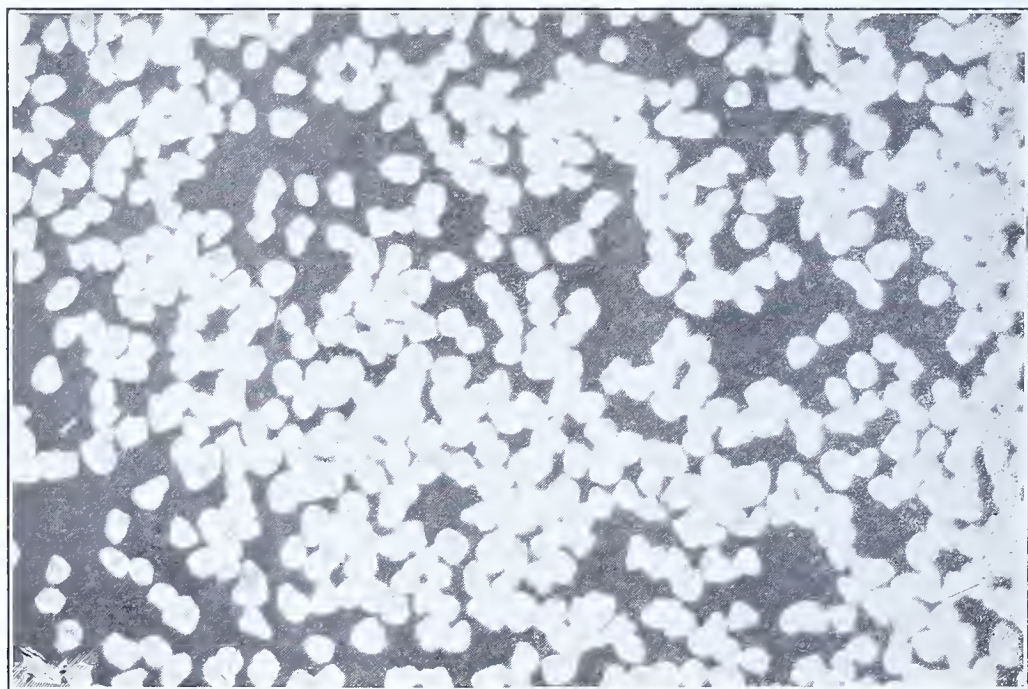
Fig. 2. Sand grains of same size, Wedron No. 1 sand.
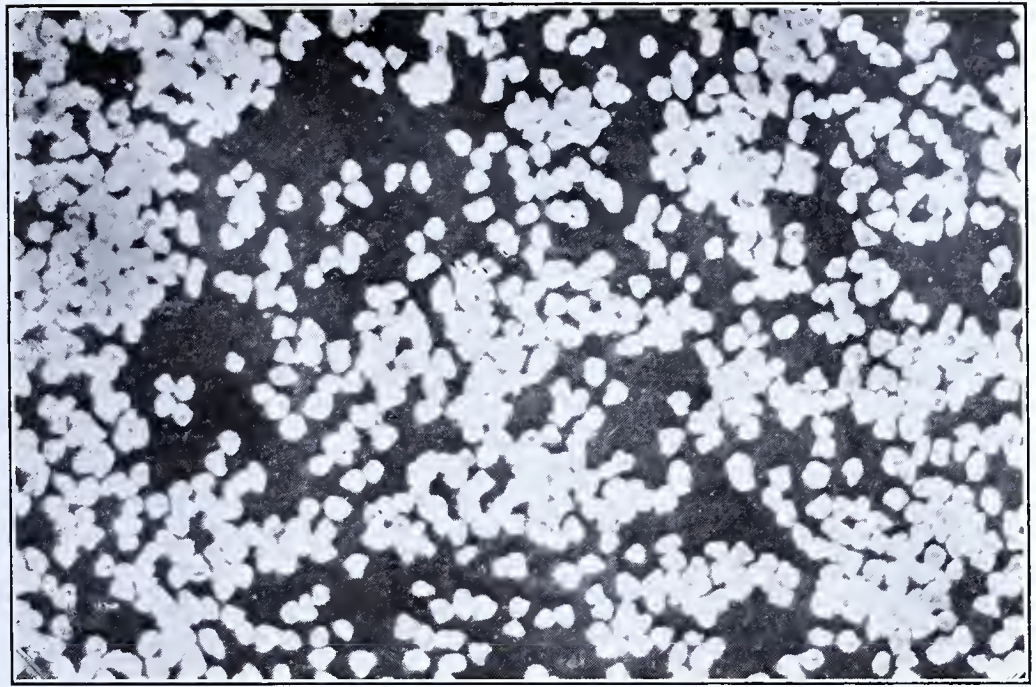
PLATE X.

Fig. 1. Sand grains passed through a 150 mesh sieve and caught on a 200 mesh sieve. Between 0.074 and 0.104 millimeters in diameter. Keystone No. 1 sand.

Fig. 2. Sand grains of same size, Wedron No. 1 sand.

PLATE XL
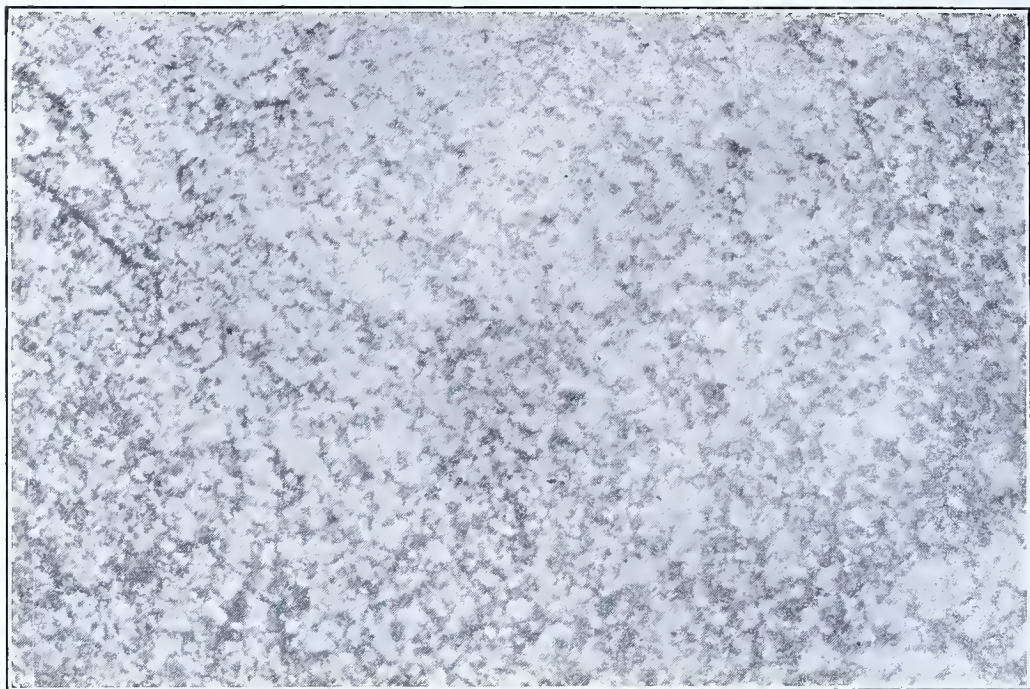
Fig. 1. Sand grains passed through a 200 mesh sieve. Less than 0.074 millimeters in diameter. Keystone No. 1 sand.

Fig. 2. Sand grains of same size, Wedron No. 1 sand.

PLATE XII.
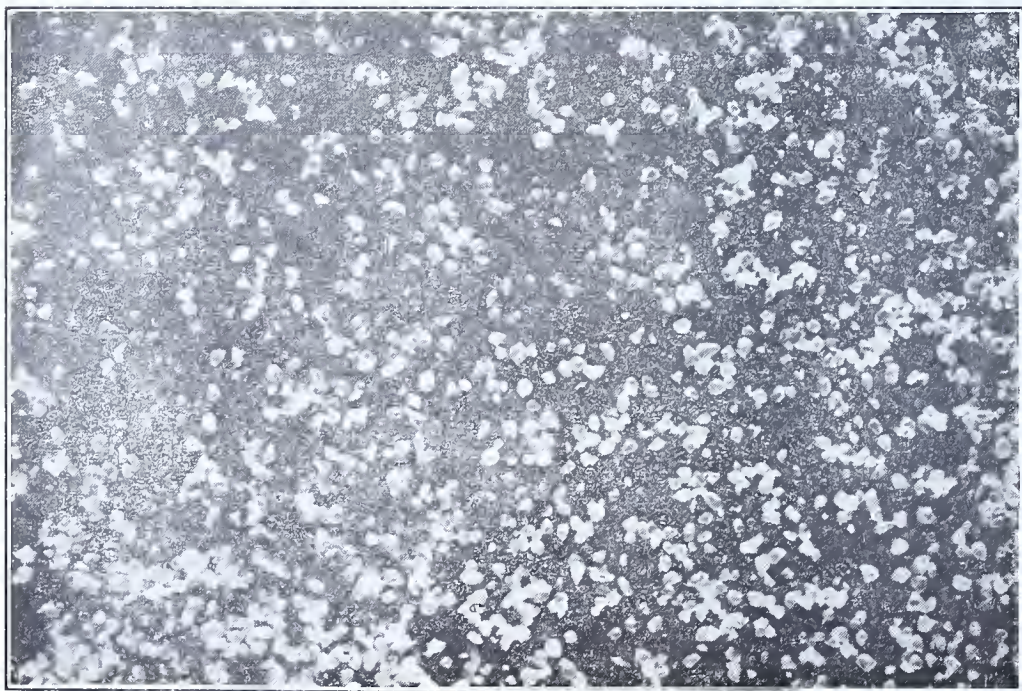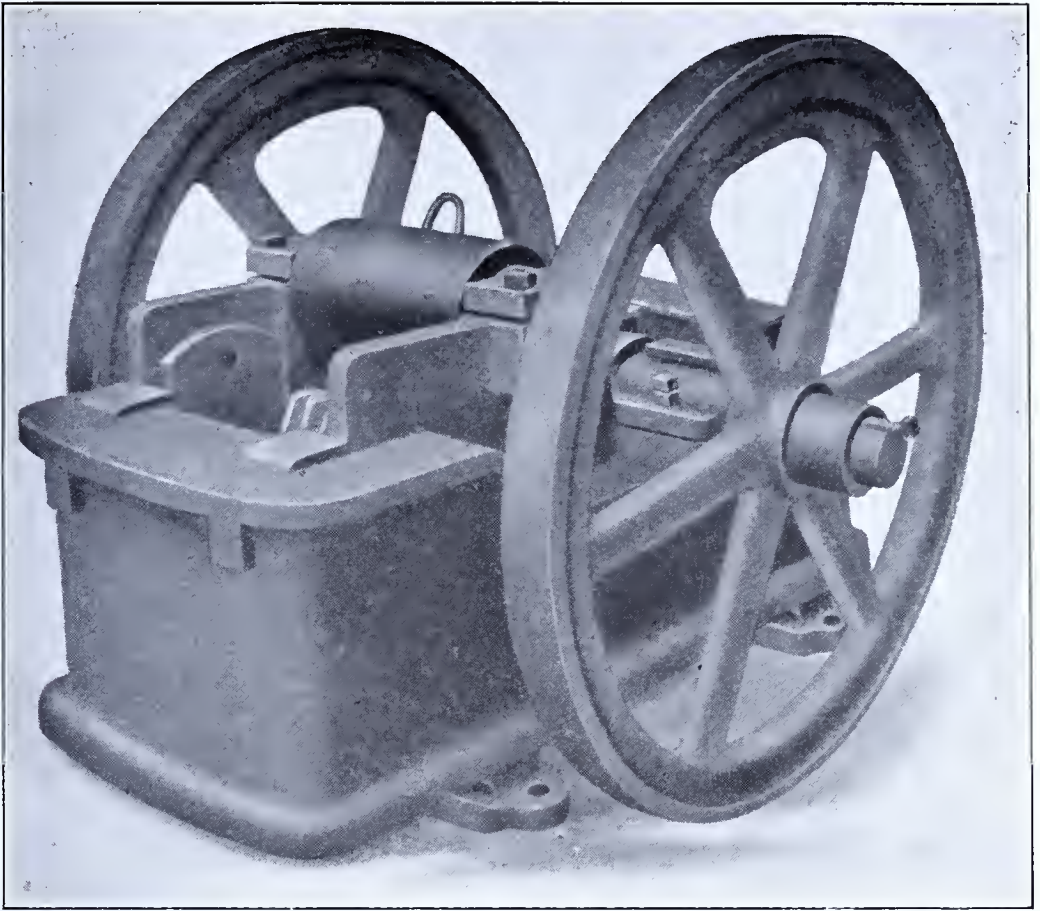
Fig. 1. Standard Blake Type Crusher. Built by Lewistown Foundry and Machine Co.

PLATE XIII.
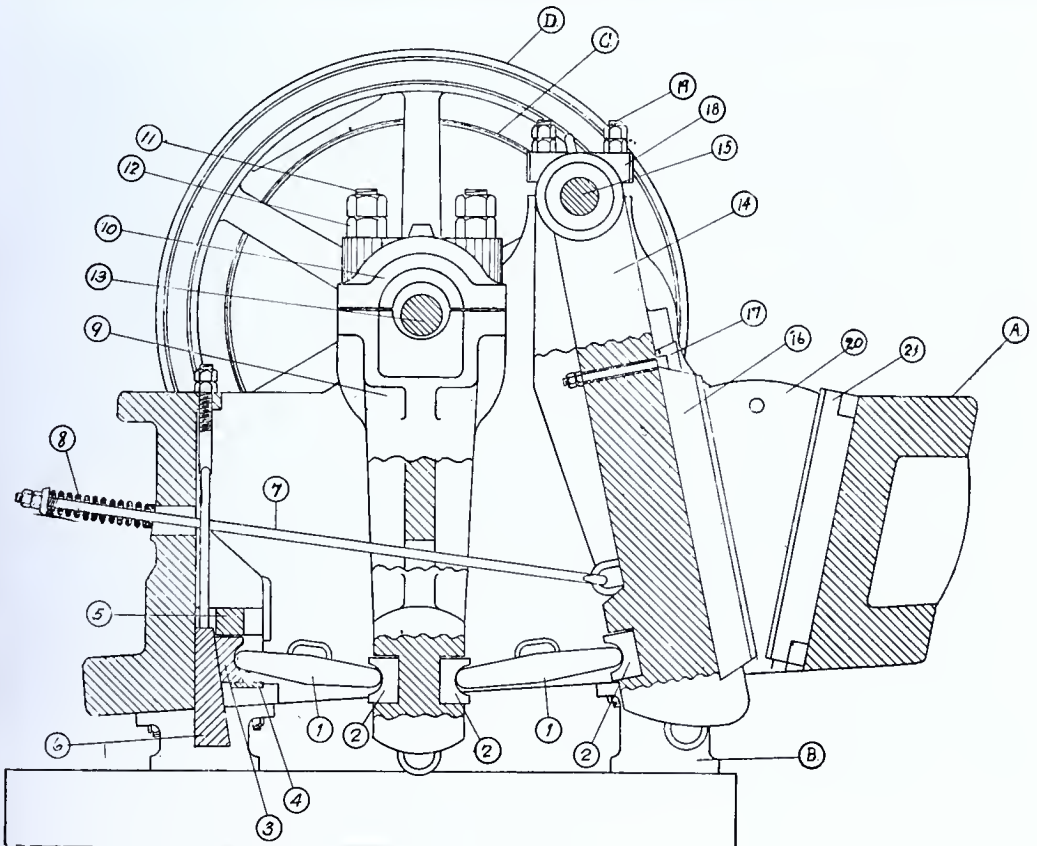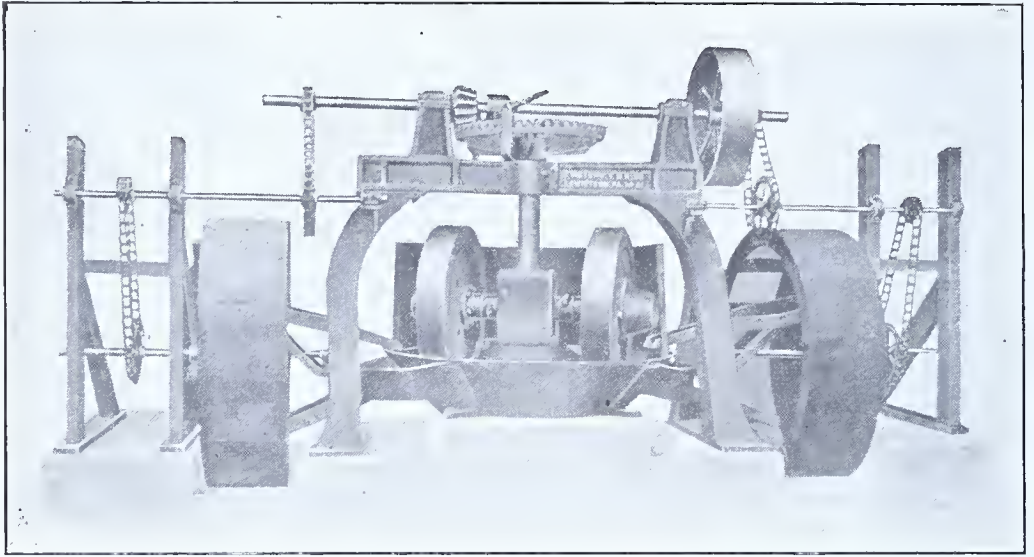
Fig. 1. Standard 8-foot Chaser Mill and Screens as built by Lewistown Foundry and Machine Company.
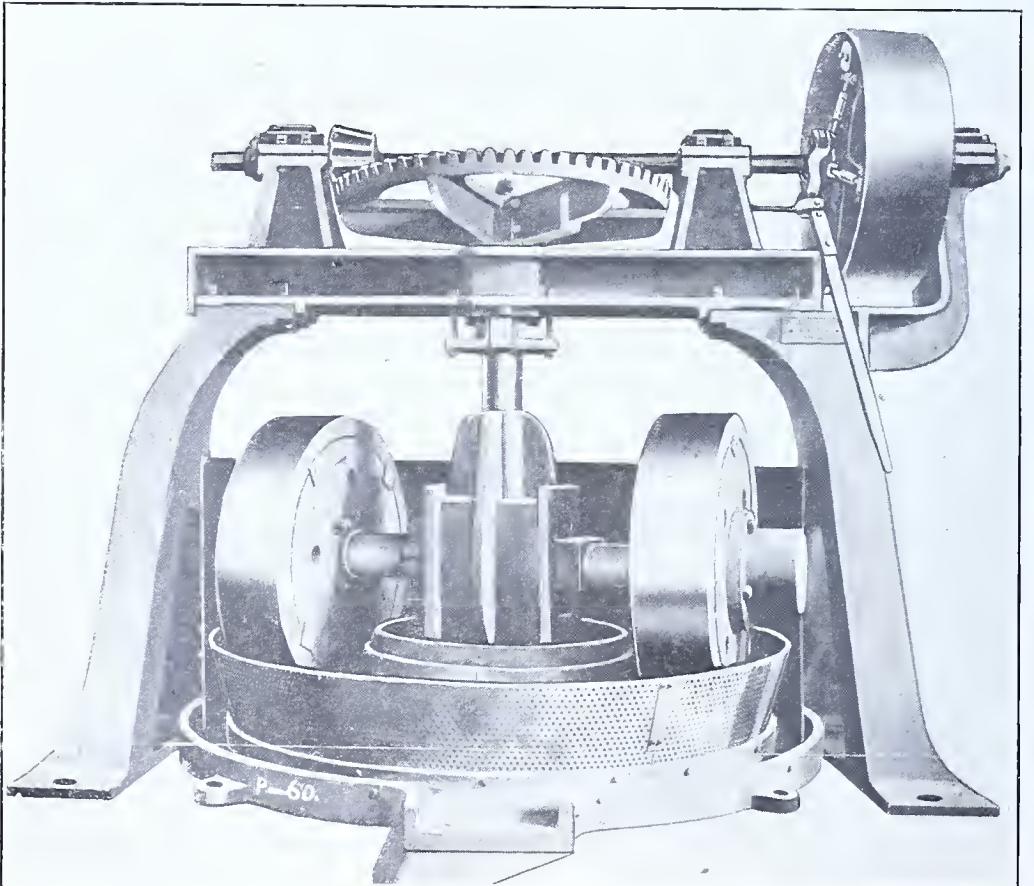
Fig. 2. Eight-foot Sand Mill as built by the Phillips and McLaren Company.

ation, therefore, reduces the alumina and ferric oxide content of the sand. When there are appreciable quantities of limonite mixed with the clayey material, therefore, it is important that the sand should be washed carefully. If on the other hand the iron is present in the sand as magnetite or some other mineral which occurs as little grains, or if the quartz grains themselves are coated with a closely adhering film of iron oxide, washing does not improve the quality of the sand to any extent.

In the wet treatment the sandstone, as it comes from the quarry, is first passed over a grizzly, consisting of a series of parallel steel rails placed about two inches apart, in an inclined position. The fine material drops into the slots between the rails while the the larger pieces pass over into a jaw crusher. The Blake type of jaw crusher is the one usually employed. Plate XII shows some of the various styles of Blake type rock crushers commonly used in Pennsylvania. A 20x12 inch crusher handles from fourteen to twenty-five tons of material per day, depending upon the nature of the rock crushed, reducing it down to about three inch diameter. It works at a speed of 250 revolutions per minute, and requires from 15 to 25 horse power to operate it.

The material from the jaw crusher and that which passes through the grizzly goes next to a chaser mill or grinding pan. Plate XIII illustrates several chaser mills and grinding pans designed for this purpose. These mills consist of circular steel pans, varying in diameter from 6 to 9 feet, in which two heavy steel rolls or mullers, mounted on horizontal axles, revolve. The pan itself is stationary. Water is fed into the pan and the material as it is crushed passes out through screens at the sides of the pan. Two opposite ends of the pan are usually perforated for this purpose. The capacity of a mill varies with the diameter of the pan and the hardness of the material treated. A nine foot pan will handle anywhere from 100 to 250 tons of material per day of ten hours, depending upon the readiness with which the sandstone crumbles under the mullers. For a nine foot mill the rolls usually have a 12 inch face, and weigh from five thousand to six thousand pounds each. They revolve about the central shaft at from 30 to 33 revolutions per minute, and require about 35 horse power to operate them.

From the chaser mill the material goes to a revolving screen. Sometimes only one screen is used, sometimes two, placed at opposite sides of the pan. Figure 1, plate XIII, shows these screens in place. They have a diameter of from 7 to 8 feet and a 24 to 36 inch face. They revolve about a central spindle at about fifteen revolutions per minute. These screens are made of brass wire with from 10 to 12 meshes per linear inch. The undersize material passes through the screen to the washer, while the oversize is returned to the chaser

mill. Occasionally when there is apt to be considerable coarse material present the sand is run through two of these revolving screens, the first one having only about six meshes per linear inch, while the second has twelve. This is done to protect the finer screen with the smaller diameter wire from too rapid wear by abrasion from the course particles of rock.

From the revolving screens the undersize material goes to the sand washers. These consist of inclined wooden boxes or troughs, ten to twelve feet long and 18 to 22 inches wide on the inside. In these troughs are cast iron rotating screw conveyors, with wide blades, which carry the sand from the bottom to the top of the troughs. Plate XIV shows the appearance of these screw washers and illustrates the way in which they are set up. About one horse power is required to operate each screw. The washers are set up in batteries of two, three, four, five, and sometimes six washers each. They may be set up either parallel to one another or in tandem. Plate XV shows three batteries of three screws each arranged in tandem. The troughs are inclined at angles varying from 18 to 20 degrees from the horizontal. The sand enters each washer at the foot, while water runs in at the head. The revolving screws thus carry the sand up the trough against the stream of water, which carries away with it the fine clayey material present in the sand. When the sand reaches the head of one washer, where they are arranged in parallel, it is dumped into a trough and is carried to the foot of the next washer by a stream of water. It passes on up this washer in a similar manner, and thus on through the other washers of the battery. Where the washers are set up in tandem they are so arranged that one washer discharges into the lower end of the next one, and so on through the series.

A plant with a nine foot grinding pan requires at least 150 gallons of water per minute. In some plants 400 to 600 gallons are used. An adequate supply of water, therefore, is an absolute necessity for a washing plant of this type.

If the sand is to be shipped wet it is ready for the cars after leaving the washers. If it is to be dried it goes to the draining sheds, where the excess water is allowed to run off. The sand from the washers is discharged onto a rubber conveyor belt, inclined at the end near the washer and horizontal at the end over the draining floor. The belt runs near the roof of the draining shed and the sand is allowed to drop from it so as to build up large cones, reaching from the floor to the belt. These sheds ordinarily have sufficient length to permit discharging at various points along the belt, and thus several of these cones of sand may be built up. The sand is usually allowed to drain at least twelve hours.
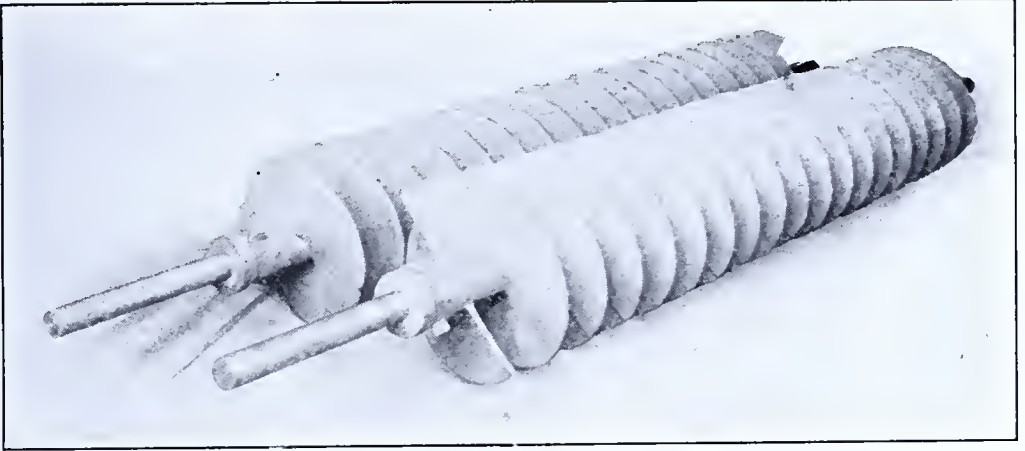
PLATE XIV.

Fig. 1.   Double Flight Sand Washing Screws (cast in one piece).   As manufactured by Phillips and McLaren Co.
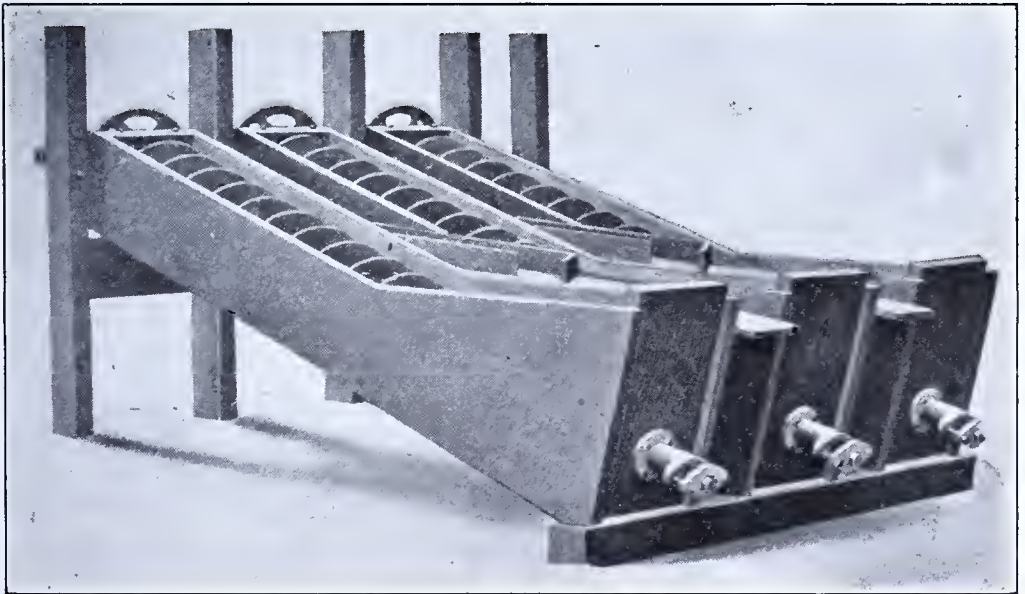
Fig. 2.   Three 18 inch by 12 foot washers arranged in parallel.   As manufactured by Lewistown Foundry and Machine Co.

PLATE XV.
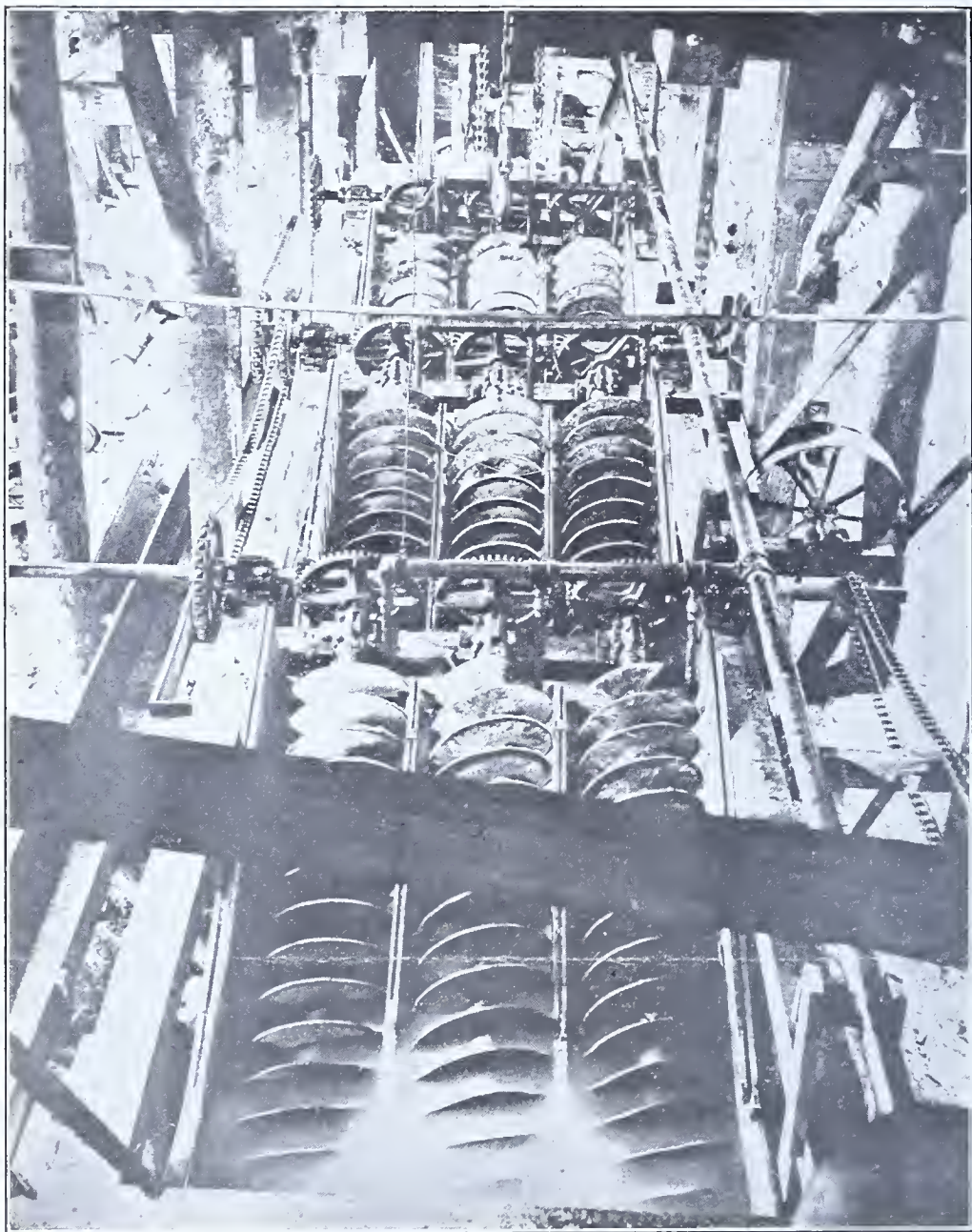
Three batteries of three screws each arranged in tandem. Erected by Phillips and McLaren Company.

PLATE XVI.
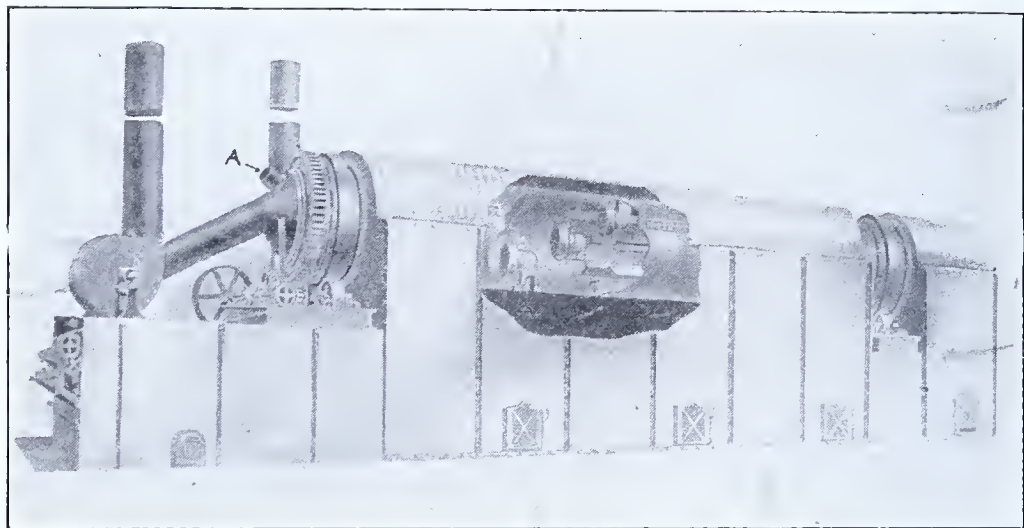
Fig. 1.   Cummer style "F" dryer.   Self-contained, with exhaust fan.
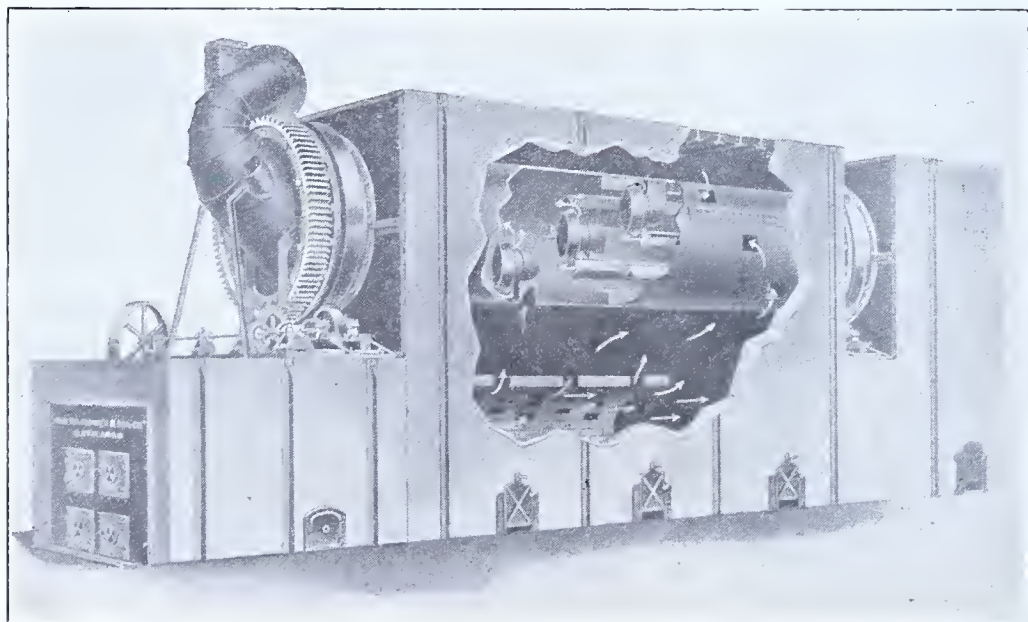
Fig. 2.   Cummer dryer.   Semi-self-contained type, with disc fan.

After the surplus water has been drained off, the sand is ready for the dryer. It is usually shoveled by hand onto a bucket elevator which carries it to a horizontal belt conveyor running to the dryer. This bucket elevator is so arranged that it can be moved about from place to place in the draining shed.

There are several types of dryers in use. Of these the steam dryer is the most recent invention and is gradually replacing the others. Steam dryers are usually built in sections about 20 feet long, 8 feet wide and 6 feet high, with hopper shaped bottoms. The walls of the dryer are built of ordinary red brick. Inside are horizontal steam pipes resting on inverted angle irons. These pipes are arranged in tiers one above the other, and are placed closer and closer together towards the bottom of the dryer. The sand is discharged onto these pipes from a belt conveyor running over the dryer, and gradually drops down between them and finally is discharged onto another belt conveyor at the bottom of the dryer. The pipes are heated by passing steam through them. This evaporates the water in the sand. The resulting steam and damp air accumulate under the angle irons on which the pipes rest, and are drawn off by means of an exhaust fan.

Direct heat dryers are also used in the drying of sand, although they are no longer as popular as formerly, and in many plants are being replaced by steam dryers. The Cummer Salamander Type of Direct Heat Dryer, manufactured by the F. D. Cummer & Son Co. of Cleveland, Ohio is the style of this type of dryer most frequently found in Pennsylvania sand plants. A Cummer dryer consists of a revolving steel plate cylinder, carried on steel tires, which run on steel rolls at each end. The rolls are supported on structural steel foundation plates. Compound gearing is used for revolving the cylinder, with a reduction of 10 to 1. Figure 1, plate XVI shows the Cummer style "F" dryer, self contained type, with exhaust fan. Figure 2 shows the semi-self-contained type. The salamander type is very much similar to this, the only difference being that the internal construction of the cylinder is modified to suit it for drying sand which is not necessarily injured by overheating. The setting is also different. In this dryer the wet material is fed continuously into the dryer at the one end, through the feed spout "A", and is discharged at the rear end dried. The heated gases resulting from combustion in the furnace pass into a large commingling chamber which extends the entire length of the dryer cylinder. This cylinder, which revloves slowly, has a great many large square openings in it, each of which is covered with a cast iron hood or cap, as shown. A sufficient number of hoods are put into each cylinder to allow about three fourths of the heated air and gasses to enter the cylinder. The balance of the/heated air and gasses enter

the cylinder through the rear end. The result is there is comparatively little circulation at the rear end of the cylinder where the material is practically dry, and consequently there is little or no dust blown out through the stack.

The fan, which is located at the front or feed end of the dryer, draws the products of perfect combustion from the furnace into the commingling chamber, also air through the registers in the side walls of the dryer, which reduces the temperature towards the rear end of the dryer cylinder. The same fan draws the heated air and gasses at different temperatures from the commingling chamber into the cylinder through the hoods into direct contact with the material being dried. The highest temperature gasses enter through the front hoods in contact with the wet, cold material as it enters the cylinder. The material immediately on entering the cylinder commences to dry as it travels rearward towards the discharge, rapidly becoming more dry, the temperatures of the heated air and gases are relatively lowered by the cold air coming in through the registers in the side walls of the dryer. The drying material is constantly cascaded in the cylinder as it travels towards the rear or discharge end of the cylinder in the opposite direction to the heated air and gases. The air, gases and moisture pass into the atmosphere from the cylinder through the fan. For drying glass sands coke must be used as fuel. Where ordinary bituminous coal is used there is apt to be a coat of carbon formed on some of the sand grains, due to imperfect combustion. This is not permissable where the sand is to be used for glass making purposes.

Another type of direct heat dryer occasionally used consists of a brick stack about thirty or forty feet high. At one side of this stack is a fire box, provided with artificial draft, air being forced into the fire box by means of a blower. A bucket elevator carries the sand to a point near the top of the stack, down which it is allowed to drop. It is discharged at the bottom of the stack by means of a screw conveyor. The moisture in the sand is driven off by the heat of the rising gaseous products of combustion through which it falls. Coke must be used as a fuel for the same reason as in the case of the Cummer dryer.

One of the objections against the direct heat dryers is, that if they are not carefully watched the sand is apt to become heated to a temperature that sets fire to any wood work with which it comes in contact. Disastrous fires have resulted from this cause. It is also claimed by those who have installed the steam dryers that the cost of operating them is less.

After the sand has been dried it is screened. The size of screens varies in different plants, sizes from 14, 16, 18, 20, to 22 meshes per linear inch being employed. Eighteen meshes per inch is probably
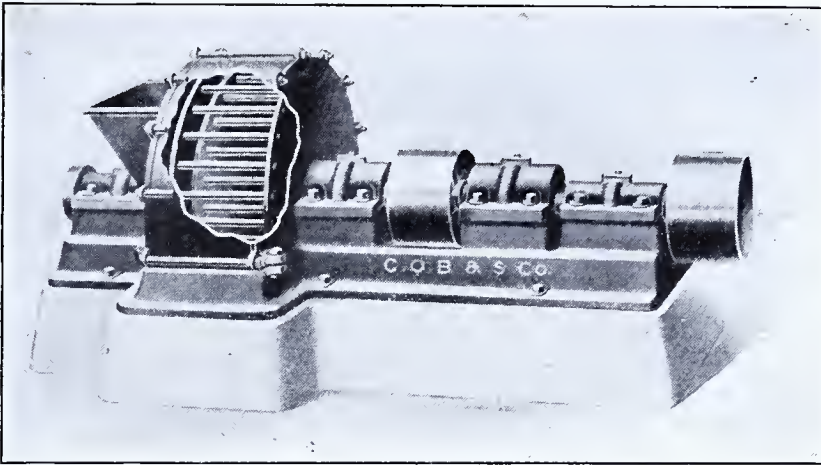
PLATE XVII.

Fig. 1. Style "A" Triumph Steel Disintegrator, as manufactured by C. O. Mart-
lett and Snow Co.
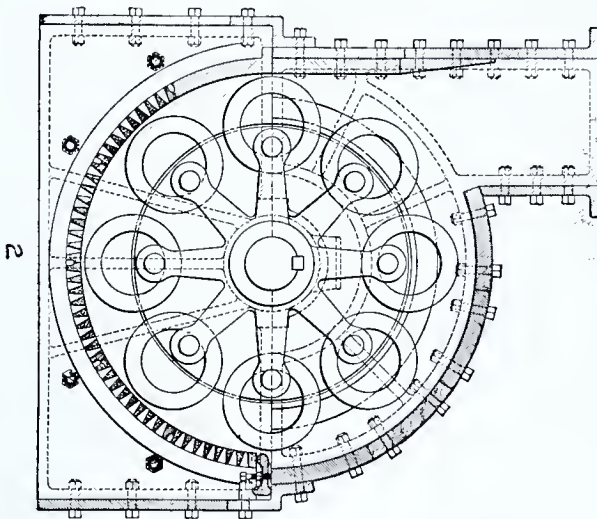
Fig. 2. Cross section of No. 24 Pulverizer, as manufactured by the American
Pulverizer Company.
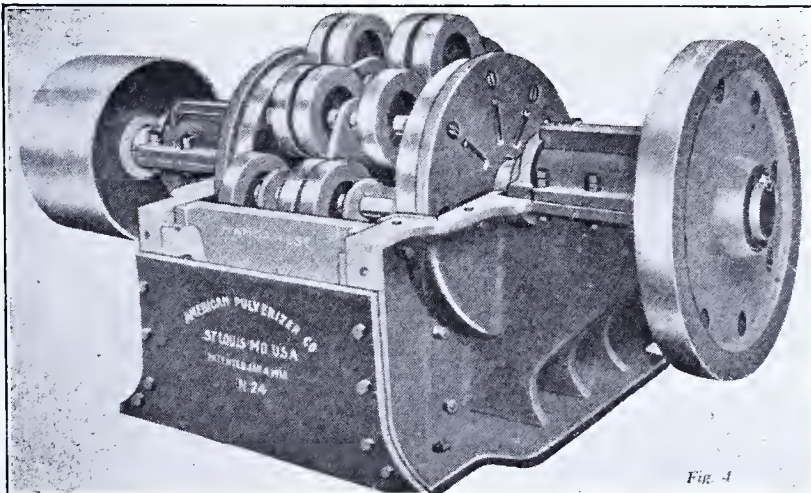
Fig. 3. No. 24 Pulverizer, with top removed.

PLATE XVIII.
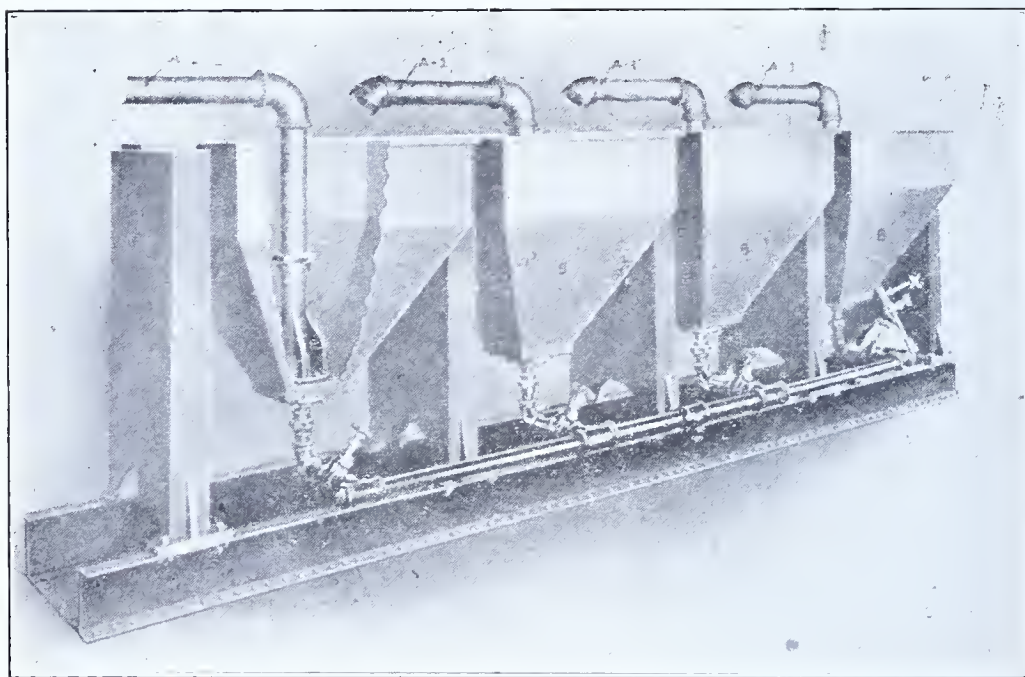
Water Jet Sand Washing Plant, as manufactured by Schutte and Koerting Co.

the most common size used. After the sand has been screened it is elevated to the storage bins, ready for shipment.

Some of the larger and more modern sand plants of Pennsylvania are capable of producing three hundred tons of dried sand per day, and cost in the neighborhood of $45,000 to erect, according to figures quoted by the Lewistown Foundry and Machine Company. This includes all the equipment and buildings, also erection costs. Phillips and McLaren of Pittsburgh estimate that the machinery for turning out two hundred and fifty tons of wet sand per day, including a 20″ x 12″ Blake crusher, a nine foot grinding pan, a revolving screen, and the necessary sand washers, cost about $4,000. This does not include the wooden boxes for the washers.

Thomas Carlin's Sons Company of Pittsburgh, furnished the writer with the following cost data for erecting a 100 ton daily capacity wet sand plant.

Electric Power.

1 8′ pan, without pulley and pinion shafe, but with double screens,	$1,350 00
1 20″x12″ crusher,	600 00
5 Screw washers, 14″x10′,	600 00
1 9′x32″ revolving screen,	250 00
1 Elevator,	250 00
Line shaft, pulleys and bearings,	187 00
Belts,	185 00
1 50 H. P. 220 volt, 3 phase, 60 cycle, 695 R. P. M. motor,	600 00
1 30 H. P. 220 volt, 3 phase, 60 cycle, 865 R. P. M. motor,	415 00
Erecting machinery, including transportation and board of men,	500 00
Lumber and carpenter labor,	650 00
Foundation bolts and pipe,	100 00
Engineering and drafting,	100 00

Steam Power.

1 8′ pan,	$1,300 00
1 20″x12″ crusher,	600 00
5 Screw washers,	600 00
1 8′ screen,	200 00
1 Elevator,	210 00
Line shaft, pulleys and bearings,	222 88
1 Rubber belt, } Either can be used, }	266 11
1 Ruboil belt, }	249 26
1 100 H. P. engine,	569 00
1 Boiler and fittings,	600 00

(It must be understood these figurese are as of the time given, and subject to constant changes in prices of material and supplies.)

A Number 1, Semi-self contained Cummer Salamander Dryer of 12 to 15 tons capacity per hour costs from $2,400 to $2,500, complete. The iron work costs about $2,200. It requires 18,000 red brick and 2,500 fire brick to erect, and about 10 H. P. are required to operate it.

In the above estimate no figures for the erection of bins and suitable buildings to house the machinery are included.

Instead of the chaser mill or grinding pan for crushing the sandstone other types of disintegrators are occasionally used. Figure 1, plate XVII shows the internal construction of the style "A", triumph Disintegrator, manufactured by the C. O. Bartlett and Snow Co., of Cleveland, Ohio. The style "B" machine, which is adapted to

breaking up sandstone of the type suitable for glass sand, is of similar construction, but is heavier, and made of a better grade of material. The two sets of spokes, which are made of high grade Swedish iron, revolve in opposite directions. The sandstone as it falls between them is caught and crushed. A No. 2 disintegrator of this type, having a diameter of 36 inches and a speed of 400 revolutions per minute, has a capacity of 30 tons of sandstone per hour. The Warren Silica Company, at Torpedo, Penna. uses such a disintegrator. They find, however, that with the kind of rock they are crushing they can only get a capacity of 20 tons per hour.

The American Pulverizer Company, of East St. Louis, also manufacture a pulverizer designed to crush sandstone to sand. The grinding is accomplished by means of revolving rings, weighing about 27 pounds each, made of manganese steel or semi-steel chilled iron which are placed between grate bars of manganese steel. The rings and bars do not touch, but as the sandstone is carried between them it is crushed by impact. The machine is operated at a speed of 600 revolutions per minute. Figures 2 and 3, plate XVII, illustrate the construction of this pulverizer. The material should be reduced to pieces not over two inches in diameter in a gyratory or jaw crusher before it is fed to the pulverizer. A No. 24 Pulverizer of this type will reduce about 15 to 20 tons of sandstone to sand per hour.

One of the difficulties encountered in using disintegrators and pulverizers of the above types to crush material which is as hard as the quartz grains of sandstone is the excessive wear of the grinding parts. This makes it necessary to replace them at frequent intervals. Some iron is thus introduced into the sand in this manner, which of course is another objectionable feature, especially in the case of the better grades of sand.

For washing sand the Schutte and Koerting Co. of Philadelphia have designed a water jet and washing device, illustrated in plate XVIII, which operates on a different principle from that of the screw washer commonly used for this purpose. This consists of a series of iron boxes B, placed in one or more rows, or in a circle, with a water jet eductor A installed in each box. In the first box the sand which is to be washed is admitted at I, and at the same time is stirred by means of a clean water jet at X. The sand eductor is operated by means of clean water taken from pressure pipe P and lifts the sand to the second box. As the sand is heavy it drops to the bottom of the box, while the water mixing with the clayey material on account of the violent stirring rises and overflows near the top. In this way there is obtained a cleaning of the sand by the use of clean pressure water only, without the assistance of any mechanical means. It is desirable that the water
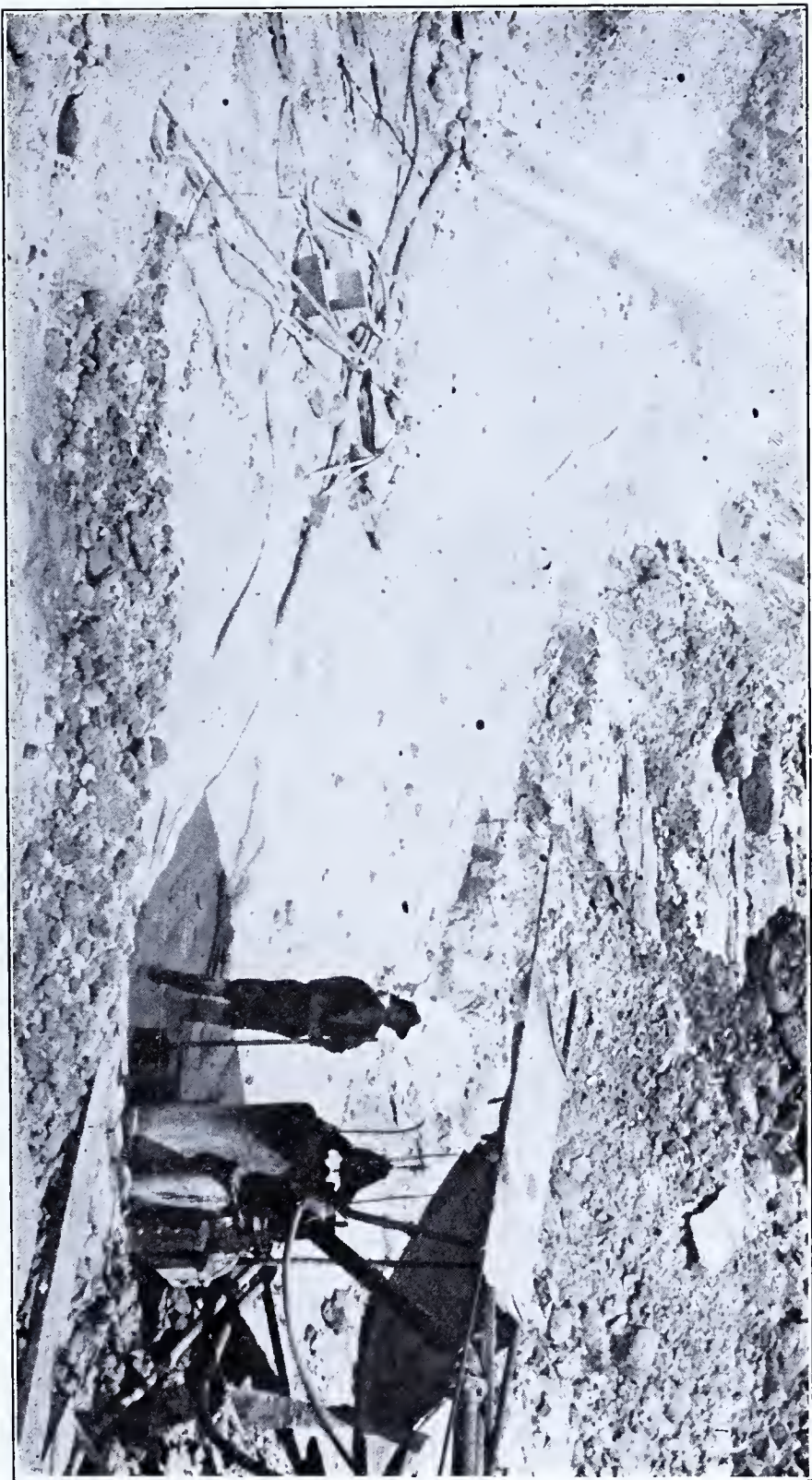
PLATE XIX.

Washing sand by water jets to a No. 5 Nye Pump, after blasting.

PLATE XX.
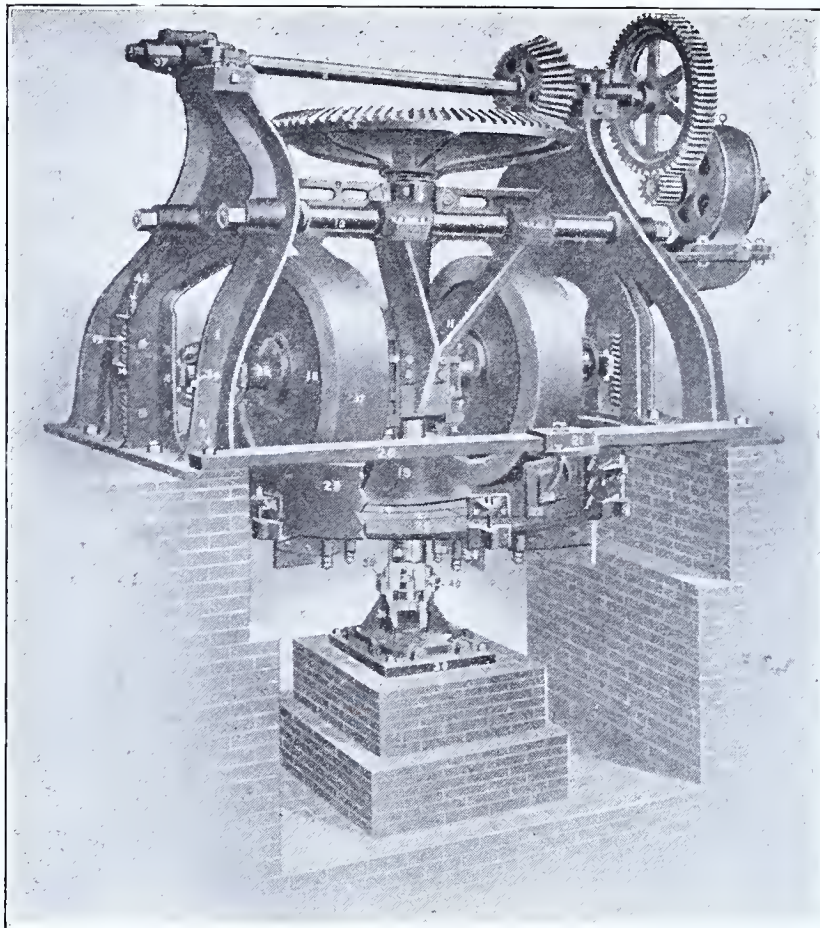
Fig. 1.　9-foot Iron Frame Dry Pan, motor driven, as built
by the Stevenson Company.
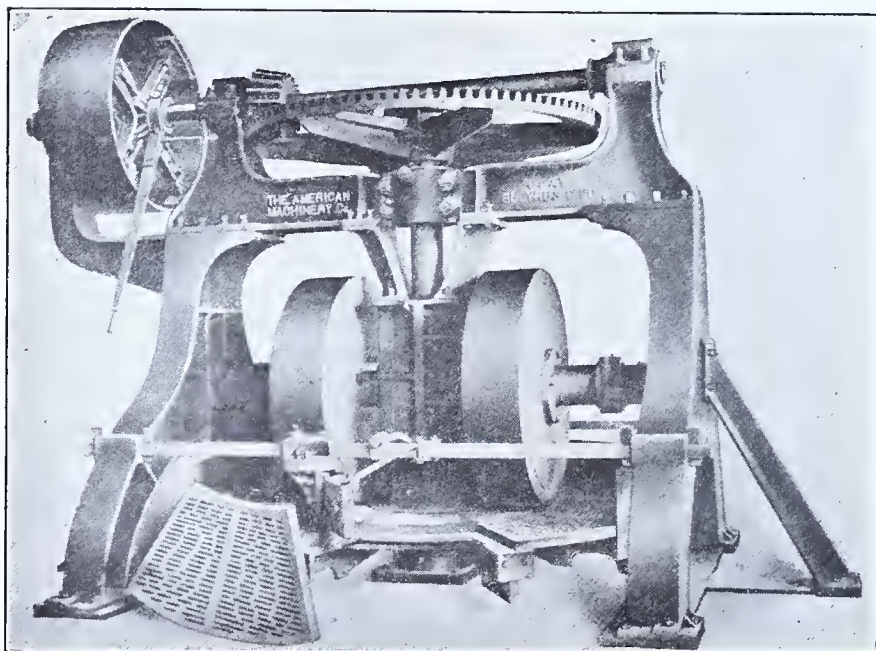
Fig. 2.　9-foot dry grinding pan, pulley driven, as built by the
American Clay Machinery Co.

be as clean as possible and the pressure at the eductor should be under a head of 30 to 40 feet. These boxes are made in two sizes; No. 1 having a capacity of 140 cubic feet of sand per hour and costing $120 per box, and No. 2 having a capacity of 210 cubic feet per hour costing $200. Two and one half cubic feet of water are required per cubic foot of sand. The number of boxes through which it is necessary to pass the sand depends upon the amount of clayey material present.

When the sand occurs as loose, unconsolidated material, the necessary plant to prepare it for the market is much simpler. No jaw crusher, chaser mills, grinding pans, or other crushing devices are necessary, the sand going directly from the quarry to the washers. It may be loaded into cars and thus transported to the plant, or if there is sufficient slope from the quarry to the washers, it may be washed into sluices by means of a stream of water played against the sand bank and thus transported. Sometimes if the bottom of the sand deposit is below the level of the washer, it is first washed into a sump by means of a stream of water, and then pumped through pipes to the washer by means of a sand pump. Plate XIX shows a No. 5 Nye Sand Pump, manufactured by the Nye Steam Pump and Machinery Co. of Chicago, installed in a sand pit. A pump of this type, with a six inch suction and five inch discharge pipe, handles ninety tons of sand per hour. The sand is first blasted down from the face and is then washed by water jets to the pump, which forces the sand and water through pipes to the washer.

Sometimes the cheaper grades of glass sand are not washed, the sandstone being simply crushed and screaned. When this method of preparation is used a different type of grinding pan is employed. Plate XX illustrates types of dry grinding pans desinged for this purpose. In a pan of this type the mullers or rolls do not revolve about a central shaft, although they turn about the horizontal axis on which they are mounted, but the pan itself is rotated. The rolls run on false plates which may be renewed when they are worn, while the outer portion of the bottom of the pan consists of screen plates through which the crushed material passes. After the material has gone through the grinding pan it is conveyed to a revolving or shaking screen, from which the undersize is conveyed to storage bins, stock piles, or directly to the cars, while the oversize goes back to the pan.

Glass sands occasionally occur in nature in which most of the iron is present in the form of little grains of magnetite (Fe_3O_4) or Ilmenite ($(FeTi)_2O_3$). Both these minerals are attracted by a magnet and, therefore, magnetic separation can be resorted to to lower the iron content of the sand. Some iron also gets into the sand from the machinery. Quartz is a hard substance and as the wearing parts of the machines in which sandstone is crushed are of iron, fine

particles of iron get into the sand through abrasion. A magnetic separator removes these also, as well as the magnetite and ilmenite which may be present. Plate XXI shows a magnetic separator manufactured by the Dings Electro-Magnetic Separator Co., of Milwaukee, which may be used for this purpose. The sand is charged into the hopper at the top and passes down a vibrating conveyor under the magnet, which picks out particles of iron, magnetite or ilmenite which may be present and carries them beyond the sides of the conveyor where they are dropped into a hopper. The writer does not know of any sand plants where magnetic separation is employed, and of only one glass factory where the sand used is treated in this way.

Kümmel and Gage[19] have called attention to the fact that many of the minerals containing iron that are apt to be present in glass sands pass an 80 mesh sieve. Cleansing the sand by screening therefore is possible. They carried on experiments in the laboratory with two samples and obtained the following results:

Screening Tests on Sands.

	First Sample.		Second Sample.	
	Before Screening.	After Screening.	Before Screening.	After Screening.
Fe_2O_3, _____	.0063	.0022	.0114	.0029
TiO_2, _____	.117	.024	.234	.0434
Al_2O_3, _____	.276	.085	.366	.106

These figures show that they were able to reduce the content of iron to one third, of titanium to one fifth, and of alumina to one third or less of the amounts originally present in the sand. As far as the writer knows this method has never been tried out in actual practice, and it appears very doubtful whether it could be carried on commercially, as almost perfect screening would be required to make it successful and a considerable percentage of fine quartz sand would also be lost, as inspection of screen analyses of glass sands will show.

Tscheuschner[20] describes a rather expensive method for purifying yellow sands which contain considerable quantities of limonite. For this purpose 64 parts of sand are sprinkled with 8 parts of water, to which 3 parts of salt and 2 parts of concentrated sulphuric acid have been added. The whole is placed in a container lined with lead, and allowed to stand for several months. The iron gradually goes into solution as the chloride. Finally the sand is carefully washed and dried. This method was at one time used in Europe in localities where pure white quartz sands were not available, but with

19. Geological Survey of New Jersey, Annual Report for 1906, pp. 77-96.
20. Handbuch der Glasfabrikation, 5th. edition, Weimar, 1885.

PLATE XXI.
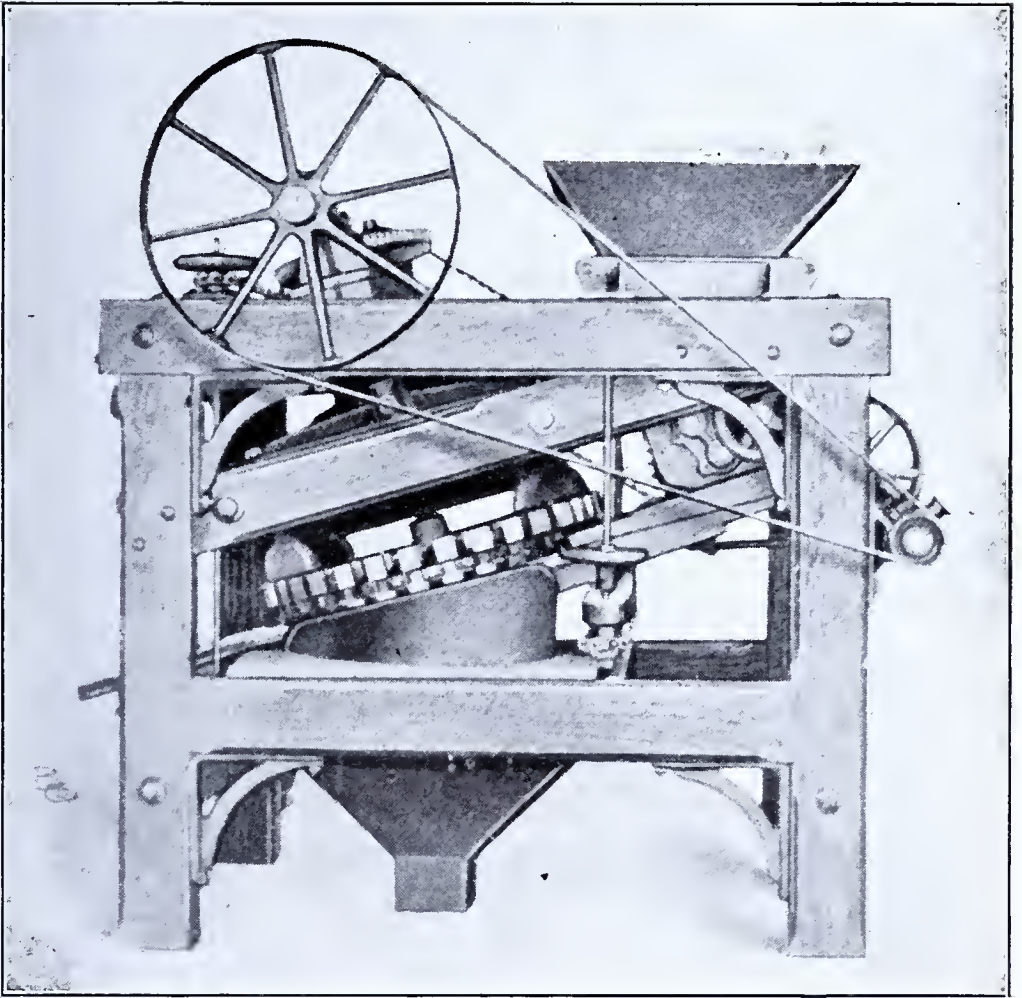
No. 2. Type MM Single Magnet Separator as built by Driggs Electro-Magnetic Separator Co.

improvements in transportation facilities it became obsolete. Glass manufacturers have never resorted to such methods in this country on account of the ease with which high grade quartz sands that require no such expensive treatment may be obtained.

Other sources of silica besides quartz sand have been made use of in the past in the glass industry, but at the present time their use has been practically discontinued. One of these is massive quartz, occuring as a vein filling in fissures in the earth's crust. Before this quartz can be used it must be crushed, which is an expensive operation. It was, therefore, early in the history of the glass industry replaced by quartz sands in which the grains are already of the required fineness.

An attempt was recently made[21] to revive the use of ground quartz as a substitute for glass sands by manufacturers at San Francisco and Los Angeles, California, because deposits of high grade glass sands have not as yet been discovered on the Pacific Coast, while massive quartz, occuring as filling in fissures, is abundant. The attempt, however, was a failure. It was found cheaper to import glass sand from other portions of the United States than to crush the massive quartz to the necessary fineness.

Flint was also employed at one time as a source of silica in glass. The term "flint glass" which still survives in the glass industry, was derived from this usage. Flint consists of an intimate mixture of quartz and opal. It has a dark gray to black color and is extremely compact, so that it has the appearance of a homogeneous substance. The fracture is conchoidal, and chips have a translucent edge. The coloring matter consists of organic material and disappears when the chip is heated before the blow pipe. Flint occurs in chalk, in the form of irregular nodules or concretions, which vary widely in size. When examined under the microscope it is often found to consist of the hard, siliceous parts of various organisms, chiefly sponges and radiolarians which lived in the seas in which the limestones were deposited. The silica was first derived from the sea-water by these organisms and when they died their skeletons accumulated on the ocean floor, together with the more numerous calcareous skeletons of other organisms which furnished the material for the chalk. Afterwards, this silica again went into solution and was chemically deposited around certain centers, and in certain places when favorable conditions obtained thus forming the flint nodules and concretions as they exist today in the chalk deposits.

Such concretions are often abundant in the chalk beds along the northern coast of France and the southern coasts of England, and in the Danish Isles. They are there freed from the chalk by

21. Mining and Scientific Press, Oct. 16, 1915, pp. 599-600.

wave erosion and accumulate along the beach, where they were formedly obtained for glass manufacture. They are no longer gathered for this purpose, however, as they have become much more valuable as pebbles for grinding in tube mills, to which their use is now restricted. Quartz sands are a much more desirable and cheaper source of silica and have, therefore, replaced them as a source of silica even in those localities in Europe where flint was formerly used.

Before opening up a new glass sand deposit and installing the necessary machinery to prepare the sand for the market, a number of factors upon which the success of the enterprise will depend must be taken into consideration. Of course it is first necessary to determine whether the sand stone or sand is of sufficient purity to allow it to be employed in the manufacture of glass. The size of the deposit must next be taken into consideration. A careful investigation should be made to determine whether it is sufficiently large to warrant the investment of the necessary capital for buildings, machinery, etc., which are needed to operate a glass sand plant.

Variations in the texture or composition of the sand or sandstone, both across and along the bed should be looked for, as these often occur due to slight variations in the conditions under which the sand was deposited. Portions of a bed thus often become too high in iron to be used for glass manufacture, and have to be sorted out from the sandstone, which increases the cost of production. Likewise, lenticular shaped masses of conglomerate often occur in beds of sandstone. On account of their pebbly nature they also have to be sorted out.

Attention has already been called to the fact that the sandstone should be rather friable and the rock should break down fairly readily along the cementing material between the grains and should not be of such a nature as to break across the grains rather than along the bond.

The geologic structure of the deposit must also be considered. If the beds are inclined or tilted it must be remembered that they can only be followed down on the dip a relatively short distance until underground mining methods become necessary. This can be done profitably only under very special conditions, when the sand deposit is an exceptionally pure and extensive one, and mining conditions are favorable. When the beds are horizontal, or nearly so, the amount of overlying material which it is necessary to strip must be determined. There may be so much of it that the deposit cannot be worked at a profit.

Where the sand is to be washed, the water supply must be examined. Sometimes this factor is neglected and sand plants are forced to shut down during the summer and early fall on account

of a lack of sufficient water to wash the sand. This may mean very serious loss.

The nearness of a market and transportation facilities are of extreme importance. Sand is a bulky material, sold at a comparatively low price, so that the margin of profit is small. The distance of various sand deposits from a certain market, therefore, is a big factor in determining which ones are able to compete for that market.

Boric Acid. B_2O_3.

Boric acid is sometimes used as a partial substitute for silica in glasses manufactured for special purposes. By replacing part of the silica of a lime flint glass with boric acid, a boro-silicate crown is obtained which is used for optical glass, thermometer tubing, and laboratory ware. When boric acid replaces part of the silica in a lead flint glass a boro-silicate flint is obtained which is also used for optical purposes and for the manufacture of enamels and "strass" for imitation gems.

Boron when it occurs in a glass is present either as boric acid or else combined with the bases as borates. It lowers the melting point of a glass and also causes it to become more fluid at any particular temperature than the corresponding silicate glass without the boron. This allows the gases to escape more readily during clarification. Boron lowers the coefficient of expansion and imparts toughness to the glass. It also gives the glass special optical properties and is used on this account in the manufacture of various kinds of optical glasses. It is also used for assisting the development of certain colors in glass. It has one disadvantage in that it causes the glass to become more susceptible to attack by acids, etc.

Boron is usually added to the glass batch in the form of borax, ($Na_2B_4O_7.10H_2O$). During fusion the water passes off leaving only the $Na_2B_4O_7$ to enter into the composition of the glass. Borax occurs as a mineral in nature, but most of the borax of commerce is manufactured artificially from the mineral colemanite ($Ca_2B_6O_{11}$-$5H_2O$). In the United States the principal deposits occur in southern California. Here borates are abundant in the dried up marshes of the desert region. Colemanite occurs over considerable areas interstratified with clays and sandstones, deposited in former lake basins whose waters have long ago evaporated. One of the most noted localities is Death Valley in Inyo County.

Phosphoric Acid and Arsenious Acid.

Phosphoric acid and arsenious acid are sometimes added to glass, the former in the shape of bone ash, which is a calcium phosphate and the latter as arsenious oxide, As_2O_3. As acid radicals, however,

they play a very unimportant role. Phosphoric acid is occasionally used in the production of certain special glasses, such as Jena phosphate crown, which contains 60% P_2O_5. The more common use for phosphoric acid in glass, however, is an opacifier, and of arsenious acid as a clarifier. These substances are, therefore, again briefly referred to under those heads.

BASES.

Alkalies.

An alkali base, either sodium or potassium, is present in practically every commercial glass. In the case of bottle, window, plate and lime flint glasses the alkali employed is sodium, while in the case of lead flint it is potassium.

Sodium Oxide. Na_2O.

Sodium is introduced into the glass batch either as sodium carbonate, called soda ash, or as sodium sulphate, called salt cake by glass men. Sodium in small quantities is also introduced occasionally as sodium chloride or sodium nitrate, but not with the object of supplying alkali. These salts assist in various ways, which are taken up later in the chemical reactions which take place when the batch is fused. The mineral cryolite ($AlNa_3F_6$), which is occasionally used as an opacifier, also contains sodium, as does borax, which has already been referred to.

Sodium carbonate is manufactured from sodium chloride (common salt or rock salt) either by the "black ash" or "Le Blanc" process, or by the "ammonia soda" or "Solvay process." The latter process is the more economical of the two, the product is purer, and there are no troublesome by-products, such as tank waste. Therefore it has gradually replaced the "Le Blanc" process.

In the Le Blanc process the sodium chloride is first converted into the sulphate by treatment with sulphuric acid. The reaction takes place in two stages as follows:—

$$NaCl + H_2SO_4 = NaHSO_4 + HCl$$
$$NaCl + NaHSO_4 = Na_2SO_4 + HCl$$

The sulphuric acid should have a strength of between 57° and 60° Baume. The first action takes place at a comparatively low temperature at the back of the furnace. When it slackens the charge is raked forward and is exposed to a higher heat, thereby causing the second reaction to take place. When the carbonate is to be used for the glass industry, lead pans are usually employed in the furnace. The sodium sulphate produced in the above manner is then

mixed with limestone and powdered coal in about the following pro-
portions:—

Sodium sulphate, -- 100 parts.
Calcium carbonate, -- 100 parts.
Carbon, -- 50 parts.

This mixture is introduced into the back end of a long reverbera-
tory furnace heated to a rather low temperature at first and is then
raked forward nearer the grate, where the tempcature is much higher,
reaching 1000° C. The mass is constantly stirred. After a while it
stiffens and a blue flame appears, indicating that the reaction is
complete. It is now worked into a ball and raked into wagons
where it rapidly solidifies. Revolving furnaces are replacing the
hand worked reverberatory furnaces.

The black ash from the furnace is of a very dark brown or gray
color, with porous fracture. It contains about 45% sodium carbon-
ate, 30% calcium sulphide, 6% calcium carbonate, and small amounts
of sodium silicate, sodium aluminate, sodium sulphide, sodium chlor-
ide, ferric oxide, and coal. Usually very small quantities of cyanide,
ferro cyanide and thiosulphate are also present.

The material is placed in tanks with false bottoms and leached
with water. The temperature is kept as low as possible, and air is
excluded from the ash by keeping it covered with water to prevent
secondary reactions from taking place in the ash, which would reduce
the yield of carbonate.

The principal impurities present in the solution obtained by the
above leaching are caustic soda, sodium sulphide, sodium thiosul-
phate, sodium ferrocyanide, sodium ferrosulphide, and traces of other
compounds. It is allowed to stand for a time that material held in
suspension may settle out. Then one of a number of methods of
purification is employed.

One way is to allow the solution to pass through carbonating
towers, where it trickles over porous substances and comes into con-
tact with a current of carbon dioxide and air. The caustic soda
and sodium sulphide are here converted into carbonate, while any
iron, silica and alumina present are precipitated. Another method
is to add manganese dioxide, MnO_2, to the solution, and pass super-
heated steam and air through it. Sodium sulphide is oxidized to
sulphate, and any iron, silica and alumina present are precipi-
tated.

The purified solution is then evaporated in cast iron pans. As
it becomes concentrated as crystalline powder, consisting of $Na_2CO_3 \cdot H_2O$, separates out. This on calcination to a red heat is converted
into Na_2CO_3. The mother liquor, which usually contains a large
amount of caustic soda and sodium sulphide, is either further puri-
fied, or else used for the production of caustic soda.

In the ammonia soda or Solvay process a pure concentrated solution of sodium chloride is saturated with ammonia. This is done in tanks with perforated false bottoms, through which the ammonia, in the form of gas, is forced. The saturated solution is then run into a carbonating tower, consisting of a cast iron cylinder forty to sixty feet high and five to six feet in diameter, in which, at intervals of three to three and one-half feet, are fixed plates with a central openings. Over these plates are placed dome shaped diaphragms, which are perforated with numerous small holes. The ammonia brine is forced under pressure into the carbonating tower through a pipe which enters near the middle of the tower. The carbon dioxide at a pressure of twenty-five to fifty pounds is forced into the lower end of the tower and allowed to bubble through the many perforated diaphragms. The following chemical reaction takes place in the tower:

$$NaCl + NH_3 + H_2O + CO_2 = NH_4Cl + NaHCO_3$$

The bi-carbonate of soda ($NaHCO_3$) is insoluble in the ammonium chloride solution and precipitate out. It is drawn off, filtered, washed with cold water and calcined in cast iron pans. The carbon dioxide liberated during the calcining operation is pumped to the carbonating tower and any ammonia given off is condensed and returned to the ammonia still. The gasses from the carbonating tower are likewise condensed to recover any ammonia which they contain. By treating the ammonium chloride formed with lime, the ammonia is regenerated. The carbon dioxide is derived from limestone, which also furnishes the lime for the regeneration of the ammonia from the ammonium chloride.

The manufacture of sodium sulphate, or salt cake, from sodium chloride by treatment with sulphuric acid is carried on by the methods outlined in the first step in the LaBlanc process. As shown two products are obtained, namely, sodium sulphate and hydrochloric acid. Salt Cake is, therefore, a by-product in the manufacture of hydrochloric acid.

When salt cake, or sodium sulphate, is used as the source of sodium it is necessary to add a reducing agent to the batch, as silica alone cannot decompose sodium sulphate under the conditions existing in a glass furnace. A certain portion of carbon, in the form of coke, charcoal or anthracite coal, must, therefore, be added to all glass mixtures containing salt cake, to enable the silica to decompose the sulphate. The reaction may be illustrated by the following equation:

$$2Na_2SO_4 + C + 2SiO_2 = 2(Na_2O \cdot 2SiO_2) + 2SO_2 + CO_2$$
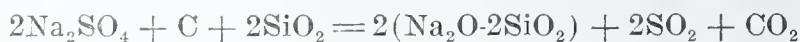
Coal to the extent of 4% to 7% of the weight of the sodium sulphate, usually 6.5% to 7%, is necessary.

There is still considerable difference of opinion in regard to the relative advantage of soda ash and salt cake as a source of sodium. Salt cake is cheaper than soda ash, the difference in price, however, is no longer as great as formerly, when all the soda ash was manufactured by the Le Blanc process. Salt cake has the disadvantage that it requires the addition of a reducing agent to the batch, which amount must be carefully regulated.

Dralle favors the use of sodium carbonate. He claims a saving of 30% in fuel by its use. The furnace may also be worked at a lower temperature, which causes it to have a longer life. The fining or clearing process proceeds more regularly and there is no formation of glass gall.

American practice, on the other hand, seems to indicate that under certain conditions salt cake may be used to advantage. For example, Gelstharp and Parkinson[22] found by experiments that in order to have no white scum or flake in a lime soda glass, where the ratio of soda to lime was less than 2:1, it was necessary to have sulphate of soda present. Frink[23] found that glass made with salt cake, the furnace conditions being the same, is harder, has a higher softening point, greater strength, and is less viscous at 845° C, than that made from soda ash, analyses showing that their composition is practically the same. Also, the molten glass made from salt cake has the property of retaining any impressions made in or upon it in the form of a cord or wave to a much greater degree than does soda ash glass, and it requires temperatures in excess of 955° C to eliminate these defects or to cause the chilled surface of the glass to again amalgamate with the main body. In the case of glass made from soda ash this takes place readily at a temperature of 900° C. Gelstharp in discussing the above paper states that plate glass made from ammonia soda ash, without any addition of salt cake, is more often reamy, and more difficult to free from fine seed than when salt cake is added, or when salt cake alone is used. He points out that the reaction between soda ash, limestone and sand takes place about 1040° C, and is finished at 1200° C, at which stage the mass is a mixture of silicates of soda and lime, with a large quantity of soda and ultimately a glass is produced full of fine gas bubbles and ream, due to the dissolving of the excess sand, the solution of which is very imperfectly mixed with the mass of the glass. To overcome this difficulty the glass must be raised to a higher temperature so that it will become very fluid. On account of the danger of the glass pots collapsing under these conditions, the heat is often shut off before the glass is perfect. On the other hand, when a certain amount of salt cake is added to the soda ash batch, a new re-

22. Transactions American Ceramic Society, Vol. 16, pp. 109-116.
23. Transactions American Ceramic Society, Vol. 11, 1909, pp. 296-319.

action is caused to take place in the melt at a temperature of 1310° C. The sodium sulphate in the presence of carbon is decomposed by the free sand, with the evolution of sulphur dioxide (SO_2). This reaction becomes especially active at 1370° C. The fine seed from the first reaction is collected together by the new generation of gas, and the molten glass is thoroughly mixed by the violent evolution of gas, so that the reaminess caused by the dissolving of the free sand disappears. Gelstharp believes that the other differences in the properties of two similar glasses, made from soda ash and salt cake respectively, are due to the presence of small quantities of undecomposed sodium sulphate in the latter.

Sodium chloride, or common salt, is sometimes added to the glass batch in small quantities. It melts at the low temperature of 800° C and thus assists in the fusion. As the temperature rises, however, it is largely lost by volatilization. In the presence of water vapor or steam it is decomposed by silica, with the formation of sodium silicate:

$$2NaCl + H_2O + SiO_2 = Na_2O \cdot SiO_2 + 2HCl$$
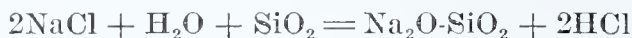
Sodium chloride is of interest to the glass manufacturer because from it are produced the sodium sulphate and sodium carbonate which are the source of the sodium in glass. Salt occurs in nature in beds of varying thickness interstratified with sedimentary rocks. These deposits were formed from bodies of salt water cut off from salt water lakes, which gradually evaporated under arid climatic conditions. At present the most important deposits from the standpoint of production occur in the states of Michigan, New York, Ohio, Kansas and Louisana.

Potassium Oxide. K_2O.

Potassium is used in place of sodium in the manufacture of lead flint glass, which is a lead potassium glass, and in Bohemian glass, which is a lime potassium glass. Potassium gives a greater brilliancy and smoothness to the glass than does sodium. On the other hand a sodium glass is said to melt clear more quickly and easily than potash glass. Potash is much more expensive than soda, and therefore it can only be employed in the better grades of glass, where low cost of production is not such an important factor as in the case of the more common varieties.

Potassium is added to the glass batch in the form of the carbonate. Up to the outbreak of the present European war Germany has been the principal source of supply of potassium carbonate for this country. Potassium salts, such as sylvite (KCl) and carnallite (KCl·$MgCl \cdot 6H_2O$) occur in vast beds at Stassfurt, Germany. From these salts the carbonate is manufactured in much the same way as sodium carbonate is prepared from sodium chloride.

Nitre (KNO_3) and orthoclase feldspar ($KAlSi3O_8$), which are sometimes added to the glass batch, also contain potassium, but these are added for other purposes than the supply of potassium to the glass.

Lithium Oxide. Li_2O.

Lithium is occasionally used in the manufacture of fine optical glass. Its rarity and cost debar it from general use.

Lime. CaO.

Lime is an important constituent of most of the ordinary varieties of glass, including lime flint, plate, window, and bottle glass. It imparts smoothness and brilliancy to the glass and greatly increases its power of resistance to chemical agents. Glass with a high proportion of lime is hard and brittle and therefore more difficult to work, and must be annealed more carefully than one with less lime. Increase in lime increases the fusibility of the glass up to a certain point, and tends to prevent the formation of cords, but it also increases the tendency to devitrify. Frink states that to increase the lime so that the glass contains more than 12.83% CaO tends to make the glass hard, brittle, and more difficult to fuse into a perfect glass. Tenacity and hardness increase up to 13.2% CaO, after which there is quite a rapid decrease in these properties.

The source of the lime used in the glass industry is limestone, a rock occuring in nature in beds interstratified with other sedimentary rocks. Calcium carbonate is present in solution in ocean waters, having been brought there by the streams whose waters dissolved it from the rocks through which they percolated. This calcium carbonate is held in solution as H_2Ca $(CO_3)_2$ by the carbon dioxide present in the water. There are a great variety of animals living in the sea that are constantly extracting this calcium carbonate for their own uses, by converting it into the normal insoluble $CaCO_3$ form. Out of it they build shells and skeletons to protect the soft parts of their bodies. Among them are such organisms as clams, oysters, corals, etc., down to forms not larger than a grain of sand, such as the foramenifera. When these organisms die their skeletons drop to the ocean floor and accumulate there, forming deposits which often reach the thickness of several hundred feet. When other sediments are laid down on top of them these calcareous sediments, by pressure, become compressed and more or less recrystallized, forming the rock called limestone. But later diastropic movements of the earth's crust they may become elevated above sea level and exposed at the surface by erosion. Calcareous deposits are sometimes formed in a very much similar manner in fresh water lakes, but these are comparatively rare.

When first deposited limestones consist of lime carbonate ($CaCO_3$), but in time in certain places they sometimes become partially or

completely converted into dolomite, CaMg $(CO_3)_2$. This change probably largely takes place while the deposits are still beneath the sea, especially when the water is warm and shallow. Sea water contains magnesium salts in solution. This change may, however, also be produced by waters containing magnesium in solution percolating through the limestone, after it has been elevated above sea level.

Limestone, therefore, is composed of calcium carbonate of varying degrees of purity, the more common impurities being magnesia, silica, clay, iron, oxide, and bituminous or organic matter. These impurities may have been deposited with the calcareous matter in sufficient quantities to give character to the rock. The terms dolomitic, siliceous, argillaceous, ferruginous, or bituminous are, therefore, often applied to limestones to describe them. The color of limestones varies with the amount and nature of the impurities present. When pure the rock is light in color, but various shades of gray to black are the more common colors on account of the impurities.

The limestones likewise show great variations in chemical composition. Magnesium carbonate may be present from traces up to the percentage amount required for dolomite $(CaMg(CO_3)_2)$. Silica may range from a trace up to the point where the rock becomes a calcareous sandstone. Similar gradations of limestone into calcareous shales occur, according to the amount of clayey material present.

In quarrying a particular bed of limestone variations in chemical composition may be encountered both laterally along the bed and vertically across its thickness. A particular stratum does not necessarily remain of uniform composition over any very extensive area. When the composition of the limestone is an important factor, therefore, as in the case of the glass industry, chemical analyses should be made from time to time.

For glass making purposes the limestone should be as pure as possible. Small quantities of silica and alummina are not necessarily detrimental. The iron content, however, must be low when a white glass is being made, but since a smaller quantity of limestone is used for a given weight of glass produced than the quantity of sand used for the same purpose, the presence of a somewhat higher percentage of iron is permissable in the limestone than in the sand. For the better grades of glass, however, Rosenhain states that the iron should not exceed 0.3%.

There is still some difference of opinion in regard to the amount of magnesia permissable in the limestone for glass making. The tendency is to allow a somewhat higher percentage than formerly. Frink[24] states that it may be present in amounts up to 6% in the

24. Transactions American Ceramic Society, vol. 11, 1909, pp. 296-311.

lime. Usually a high calcium lime, that is one containing only 0.0 to 5.0% magnesia is demanded by the glass manufacturers.

Magnesia makes the glass less soluble and lowers its coefficient of expansion. It also decreases the tendency of the glass to devitrify. On the other hand it tends to make the glass less fusible and increases its viscosity. There is not likely to be any trouble from this source, however, unless the magnesia content is extremely high. It also increases the hardness of the glass and makes it more difficult to plain.

Limestones sometimes contain flint concretions, which have already been described under silica. If they remain in the crushed stone in the form of fragments they prove very refractory, and are apt to remain as opaque enclosures or stones in the finished glass. Amorphous calcium phosphate in connection with fossil remains and silicates of lime, magnesia and alumina are also present at times in limestones. They also tend to form small white stones in the glass. The same care, must, therefore be taken in selecting a suitable limestone for glass making purposes as is observed in the case of the sand.

Lime may be added to the glass batch in any one of three different ways: either as crushed limestone ($CaCO_3$), as burnt or quick lime CaO, or as slaked lime ($Ca(OH)_2$). The burnt lime is made from limestone by heating the latter to a temperature of about 900° C in a kiln. At this temperature the carbon dioxide is driven off, as shown by the following equation:

$$CaCO_3 + \text{heat} = CaO + CO_2$$
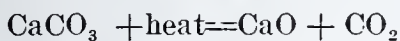
To produce slaked lime water is added to the burnt lime, which causes the following reaction to take place, with the evolution of considerable quantities of heat:

$$CaO + H_2O = Ca(OH)_2$$
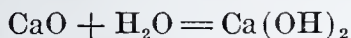
The tendency at the present time is more and more to use the ordinary crushed limestone instead of either the burnt lime or the slaked lime. With modern improvements in crushing machinery it is a comparatively easy matter to crush the limestone to the desired fineness. This was not the case in the early days of the glass industry, when the use of burnt lime and slaked lime was started.

When burnt lime is used there is a saving of heat in the furnace, because the carbon dioxide has already been removed, an operation which requires considerable heat. On the other hand the liberation of the carbon dioxide from the carbonate helps stir the glass during the melting process. One great disadvantage in the use of burnt lime or slaked lime is that the former absorbs both moisture and carbon dioxide from the atmosphere, while the latter absorbs carbon dioxide. This naturally causes the composition to vary, the amount

depending upon the conditions under which the lime is stored and the length of time. Such variations in composition naturally introduce errors into the calculated composition of the batch, unless the lime is analyzed each time before using. This is rarely done. Crushed limestone on the other hand, no matter how long it is stored, retains a constant composition.

Lime is sometimes introduced into the glass in the form of fluorite, a calcium flouride, or as bone ash, which consists of calcium phosphate. These substances are not added on account of their lime content, however, but are occasionally used to produce translucent, opal, and opaque white glasses.

Magnesia. MgO.

Magnesia is only introduced intentionally in notable quantities in special glasses, where the properties it confers are of special value. In the case of ordinary glass it often enters into its composition in small quantities on account of its presence in the limestone used.

Magnesia occurs in nature as the mineral magnesite, $MgCO_3$. This is sometimes used, but often where extreme purity is desired the artificially precipitated carbonate or else calcined magnesia is preferred.

Barium Oxide. BaO.

Barium oxide is sometimes used in the manufacture of glass. Compared with lime, barium compounds increase the density or specific gravity of the glass and gives it a higher index of refraction, so that a barium glass has a greater brilliancy than a lime glass, causing it to closely resemble a lead glass in this respect although not quite equal to it. There is also a considerable increase in the elasticity, tenacity and modulus of rupture, and a lowering of the specific heat in the case of barium glasses as compared with the lime ones. This makes barium glass very desirable for many uses, such as table ware, lamp chimneys, globes, etc. In hardness and coefficient of expansion barium glasses are practically identical with lead glasses. Barium has the advantage over lead that its silicates remain unaffected by the products of combustion, whether reducing or oxidizing, of the glass furnace, so that barium glasses can be melted in open pots or in tanks.

Barium is sometimes added, both in the case of lime alaki and lead alkali glasses. There is still considerable difference of opinion wether the barium should be used to replace the alkali or the lime, or whether it should partially substitute both. Satisfactory glasses have been made according to all three of these views. When barium carbonate is used to replace calcium carbonate, 1.97 parts of the former must be employed to replace one part of the latter. In case barium sulphate is used 2.34 parts must be employed for each

part of calcium carbonate. In this case, as in the case of salt cake, a reducing agent must be added, usually some form of carbon. Theoretically 2.7% of carbon are needed, but in practice it is found that 4% to 7% must be added. When barium carbonate is substituted molecularly for lead oxide (PbO), 0.88 parts of the former must be used to replace one part of the latter. In the case of a lead glass, barium sulphate cannot be used, as it is impossible to add carbon to a lead glass batch on account of the danger of reducing some of the lead and thus blackening the glass.

Some of the disadvantages of using barium are, as pointed out by Frink[25], that when a barium glass is melted in a pot or tank it has a disagreeable and unsatisfactory way of separating, stratifying, and laminating, so that when a lump is gathered and this is worked in any manner, it is quite likely to show a cordy condition. Also, if the barium exists in about the right percentage it causes the glass to devitrify very easily and rapidly. A fine brilliant polish, with hydrofluoric acid, like that obtained with lead glass cannot be produced in the case of barium glass.

Barium occurs in nature both as the carbonate, in the form of the mineral witherite, and as the sulphate, in the form of the mineral barite. The latter is more abundant than the former. It cannot be employed in connection with lead glasses for reasons already mentioned.

On account of its high cost as compared with lime, barium cannot be used in the manufacture of the cheaper grades of glass. It finds it chief application in the production of certain types of rolled glass, holloware, crystal, and table glass, and in special glasses such as Jena phosphate crown, which contains among other things 28% BaO and 60% P_2O_5.

Strontium Oxide. SrO.

Strontium is seldom used in the manufacture of glass as it imparts no special properties to the glass. It occurs in nature as the carbonate in the form of strontianite, and as the sulphate in the form of celestite.

Zinc Oxide. ZnO.

Zinc oxide is used occasionally in the manufacture of glass, but usually only in the case of certain special glasses, as optical and heat resisting glasses. A glass containing zinc has an index of refraction only a little higher than that of an ordinary lime glass. Zinc glasses have a high tenacity and compressive strength, are very resistant to chemical decomposition, and have a high fluidity and low

25. Transactions American Ceramic Society, vol. 12, 1910, pp. 370-375.

coefficient of expansion. One serious disadvantage is that a high zinc glass tends to devitrify readily. When zinc is added in large amounts to a glass batch it remains in suspension in the glass, or separates out on cooling, causing the glass to become opaque.

Zinc is added to the glass batch in the form of the white oxide of zinc, prepared artificially by the oxidation of the metal itself or of carbonate ores. This is a very volatile substance and care must be taken in its use or volatilization losses will be high.

Lead Oxide. PbO.

Lead oxide is an important constituent of lead flint glasses used extensively in the manufacture of cut glass ware and many optical glasses. Lead increases the specific gravity, or density, of glass, and gives it a high refractive index. This accounts for the brilliance of lead flint glasses which makes them so desirable for the manufacture of fancy cut glass ware. They are also softer than ordinary lime glasses and can, therefore, be cut and polished much more readily. Lead glasses are resistant to chemical action and do not devitrify readily. They are also more easily fusible and more plastic than lime glass.

Lead is added to the glass batch either as minium or red lead (Pb_3O_4), or as litharge (PbO). Litharge is produced on a commercial scale by oxidizing metallic lead. This is accomplished in cupellation furnaces, by heating the molten lead under oxidizing conditions in oval or rectangular shaped pan like hearths, placed on carriages which may be moved in and out of small reverberatory furnaces. The lead is thus converted into litharge (PbO) which when further heated at a temperature of about $300°C$, with the ready access of oxygen, is converted to red lead (Pb_3O_4). If the temperature is raised much above this, however, it will give off some of its oxygen and gain go back to litharge (PbO).

Red lead is preferred to litharge by glass manufacturers because it liberates oxygen upon heating and, therefore, creates an oxydizing atmosphere in the glass pot. This is very desirable as reducing conditions are disastrous in a melt of lead glass on account of the tendency of the lead oxide to become reduced to the metallic state, and thus blacken the glass. It is for this reason that lead glasses must always be made in closed pots, where all reducing furnace gasses can be kept from the molten glass.

Red lead for use in the manufacture of glass must be free from metallic lead and discoloring metallic impurities, such as copper and iron. The percentage composition of lead in red lead is apt to vary so much that chemical analyses are necessary from time to time to keep the composition of the glass batch constant.

Alumina. Al_2O_3.

The effect of alumina on glass has already been discussed under the heading of alumina as an impurity in glass sands. Due to its extremely slight solubility it increases the chemical resistance of the glass and also gives it valuable physical properties. Large quantities cannot be added on account of its high melting point. On account of the lowering of this by the presence of other oxides, however, it is often added up to 10%, according to Dralle.

In the case of alkali free glasses it is added in the form of the mineral kaolin ($H_4Al_2Si_2O_9$), in other cases as feldspar, usually orthoclase ($KAlSi_3O_8$). Orthoclase in conjunction with fluorine preparations is used as an opacifier. Alumina also enters into the composition of the glass when the mineral cryolite ($AlNa_3F_6$) is used as an opacifier.

Thallium.

Thallium is a rare metal which is occasionally used in the manufacture of optical glass of high refractive power. It is found in nature in certain specimens of pyrite and in some mineral waters. The metal is generally extracted from the flue dust of furnaces in which pyrite containing the element is burned. The dust is treated with dilute sulphuric acid and the thallium precipitated in a crystalline form by means of zinc.

Igneous Rocks and Slag.

Ingeous rocks consist chiefly of silicia, alumina, ferrous and ferric oxides, magnesia, lime, soda, and potash. The relative percentages of these oxides shows a considerable variation in different types of igneous rocks. Those that have a high silica content are called acid or silicious, while those which have a relatively high iron, magnesia and lime content, are called basic. From an inspection of the above constituents it is seen that these are the oxides which are present in glass and that, therefore, igneous rocks, except insofar as the iron content may interfere, can be used as raw material in the manufacture of glass. In the case of green or brown bottle glass the iron content would not necessarily be detrimental. The siliceous rocks which as a general rule also have the highest alkali content are the most desirable, because alkalies are more expensive than lime.

Igneous rocks have been used to a slight extent in Europe as a raw material by crushing and adding to them the necessary constituents, so that the composition of the batch yields a workable glass. At the best, however, only the cheapest grades of glass, such as bottle glass, may be made from these materials.

In a similar manner blast furnace slags, from the manufacture of pig iron, have been employed as raw materials in the manufacture of the cheaper grades of glass. One of the greatest difficulties in the

manufacture of glass from either igneous rocks or slag is to keep the batch uniform in composition. These materials vary greatly in composition so that numerous chemical analyses are necessary to obtain a glass of approximately uniform composition, day after day.

CLARIFIERS.

In the melting of the glass batch, when the last trace of undecomposed raw material has disappeared, the resulting glass is found to have thickly disseminated through it small bubbles of gas derived from the decomposed carbonates, sulphates, etc. In order to free the glass from these bubbles it must be heated further and more intensely. This causes it to become more fluid and, therefore, allows the gas bubbles to escape more readily. This process is known as "fining." It takes place much more readily if the bubbles are large, and in fact it is almost impossible to get rid of very minute bubbles in this way. An attempt is therefore made to prepare a batch of such composition that it will yield only large bubbles. Sometimes where this is not possible some substance is added which rapidly evolves a great many large bubbles of gas. These in their upward course sweep the small bubbles away with them. Substances used in this manner are called "clarifiers."

Arsenic Trioxide. As_2O_3.

Arsenic trioxide vaporizes without melting. It has several effects on glass in fining, the most important of which is a mechanical one. It has a higher specific gravity than molten glass, the former being about 3.7, while that of the latter is only about 2.6. Therefore when a piece of arsenic trioxide is thrown on top of the molten glass, it sinks into the melt on account of its high specific gravity, and vaporizes very rapidly. The rising bubbles stir up the glass, sweep up the smaller bubbles in it, and tend to cause it to become homogeneous.

Dralle thinks that at the same time it may have a chemical influence. It may act as an oxidizing agent, by becoming reduced to arsenic. It can then form arsenic trisulphide with sulphur. Both arsenic and arsenic trisulphide are volatile, and a purification from coloring matter due to sulphur thus results. On account of the high volatility of arsenic trioxide it is only rarely that any arsenic remains in the glass.

A further use of arsenic is to remove over coloring when an excess of selenium or manganese has been added in decolorizing, and the glass has a slight pink color. By the careful addition of arsenic this may be removed. In the case of selenium an oxidation of the selenium results. In the case of the manganese dioxide the reaction is not so well understood. The colors obtained with the other metallic oxides may also be clarified by "fining" with arsenic.

Soda Nitre, or Chili Saltpetre. NaNO₃.

Soda nitre melts at 318°C. At a little above its melting point it breaks up into sodium nitrate as follows:

$$2NaNO_3 = 2NaNO_2 + O_2$$
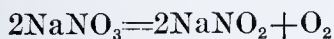
At a still higher temperature the nitrite is decomposed still further as follows:

$$2NaNO_2 = Na_2O + N_2O + O_2$$
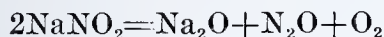
Only the sodium oxide enters into the composition of the glass. The other constituents pass off as gases. Sodium nitrate is found in large deposits in northern Chili.

Nitre, or Saltpetre. KNO₃.

Nitre is prepared artificially from sodium nitrate and potassium chloride according to the following reation:

$$NaNO_3 + KCl = KNO_3 + NaCl$$
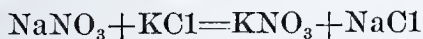
It melts at 340°C and breaks up into the nitrite at 500°C, while at very high temperatures it is further decomposed, thus behaving like the sodium nitrate.

$$2KNO_3 = 2KNO_2 + O_2$$
$$2KNO_2 = K_2O + N_2O + O_2$$

Only the potassium oxide enters into the composition of the glass.

The importance of both nitrates rests on the evolution of oxidizing gasses, which burn off organic compounds and the yellow coloring sulphur. They also facilitate fusion because they melt at comparatively low temperatures and then dissolve the more difficultly fusible constituents of the batch. The evolution of the gas also tends to stir the melt. They are not as valuable as arsenic in this respect because the decomposition has been largely completed before fining sets in.

The usefulness of salpetre lies in the fact that the bad effect of carbonaceous materials or reducing flames may be counteracted by its use. It cannot be employed, therefore, where the glass must be melted under reducing conditions, as in the case of copper red glasses, or where carbon is added to sulphate batches. The solvent power of the molten and decomposing saltpetre on the pots is bad. Its high price is also against its more common use. On account of the fact that sodium nitrate absorbs water, potassium nitrate is more desirable.

Vegetable Substances.

Frequently some vegetable substance containing much moisture is introduced into the glass to produce the desired evolution of gas. One method is to place a potato in the crook of a forked iron rod

and then to dip the rod with the attached potato into the molten glass.

DECOLORIZING AGENTS.

It has already been shown that it is practically impossible to entirely keep iron out of the glass batch, inasmuch as there are usually minute amounts of this substance present in the glass sand, limestone, soda and other materials employed. Of course the purest varieties of glass contain only the merest traces of this element. Cheaper grades, however, always contain iron in measureable quantities.

Iron may exist in the glass either in the ferrous or the ferric condition. If the glass is produced under reducing conditions, which is usually the case in a glass making furnace, the iron is present in the glass in the ferrous state. It then shows a decided greenish-blue tint, whose depth depends upon the amount of iron present, provided no "decolorizer" has been added. If an oxidizing agent is added to the molten glass the iron is brought into the ferric condition. It then colors the glass a characteristic yellow tint, which is much less intense and vivid than the corresponding green color of the same amount of ferrous iron. To overcome these color effects of iron and produce a glass which appears colorless to the eye, certain decolorizing agents are sometimes added to the glass batch.

Manganese Dioxide. MnO_2.

Manganese is one of the important decolorizers employed by the glass manufacturer. It is usually added to the glass batch in the form of the black manganese dioxide (MnO_2), which occurs in nature as the mineral pyrolusite in a form sufficiently pure to be employed for this purpose. Analyses should be made from time to time, however, to see that the pyrolusite used is free from iron, as oxides of iron sometimes occur as impurities intimately mixed with the pyrolusite. Such occurrances of the mineral cannot be used for decolorizing purposes.

When manganese is introduced into glass in the absence of other coloring ingredients a pinkish purple to violet color is produced, according to the chemical nature of the glass. The exact color produced depends not only upon the chemical composition of the glass, but also on the heat and duration of the "fining" process, and the reducing or oxidizing conditions of the furnace. Its employment, therefore, requires much skill and care in order to get the desired results.

If some iron is present in the glass batch, and a little manganese dioxide is added, instead of obtaining a colored glass, the two tints due to iron and manganese appear to neutralize one another and a glass which is apparently colorless, as far as the eye is concerned,

is obtained. Two theories have been advanced to explain this decolorizing effect of manganese dioxide. One is that the pink color produced by the manganese is approximately complimentary to the greenish blue of the ferrous iron and that the glass, therefore, transmits light of approximately neutral color. The other is that the manganese dioxide acts as an oxidizing agent, oxidizing the ferrous to ferric iron. The latter as already stated gives the glass a very light yellow tinge, so that it becomes practically colorless. There seems to be a little more evidence in favor of the first theory than the second (Transactions, American Ceramic Society vol. 13, 1911, pp. 251-258.)

The greenish blue tinge produced by iron can only be neutralized when very small proportions, not over 0.1% of iron are present. When larger quantities are present the addition of manganese modifies the resulting color, but is no longer able to neutralize it. In this country about one ounce of manganese dioxide is added to one hundred pounds of sand, while in Europe fifteen to two hundred grams per one hundred kilograms are used. The best results are obtained with lead flint, but it is also used to a certain extent in the case of the lime-soda glasses. One of the difficulties in the latter case is that when salt cake is employed coal must be added, which exerts a reducing action on the manganese, and interferes with its coloring properties. Manganese cannot be added to the glass very readily after the batch has been melted, as it sinks to the bottom and colors the mixture unevenly. The color also depends on the length of the melting process and the temperature attained.

Glass containing manganese loses its pink color to a certain extent during annealing in a lehr, making it necessary to have the glass slightly pink before it goes into the lehr, for otherwise the glass would come out with a slightly greenish-blue tinge. On the other hand glasses in which manganese has been used as a decolorizer on prolonged exposure to sunlight, or ultro-violet light, often assume a pink, purple or brown tinge.

Nickel Oxide. NiO.

Nickel oxide, which is also occasionally used as a decolorizer, exerts a powerful coloring influence on glass. The color produced depends on the chemical composition of the glass, and the state of oxidation of the nickel. It is usually of a greenish-brown tint.

In sodium glass about five grams of nickel oxide per one hundred kilograms of sand are required to act as a decolorizer, while in potassium glasses the amount is still less. Nickel does not act as a decolorizer in the presence of lead, therefore its use is confined to the lime-alkali glasses. With nickel, as with manganese, only the effects of comparatively small quantities of iron can be neutralized.

Selenium. Se.

Selenium can be used as a decolorizing agent for glasses of a certain chemical composition.   Under suitable conditions selenium produced a yellowish pink coloration, the intensity of the color depending upon the chemical nature of the glass and the amount of selenium left at the end of the melting process, this in turn depending upon the duration and temperature of the fusion.   The pink color can be best developed in glasses containing barium as a base, but lime-potash glasses also give satisfactory results.   It is not very successful in the case of lime soda glasses, and when added to a lead glass there is a tendency to develope the black selenide of lead, which prevents its use as a decolorizer in this type of glass.

In the case of the lime potassium silicate glasses selenium gives very satisfactory results as a decolorizing agent to neutralize the color effects of small amounts of iron present in the glass.   One to one and one-half grams of selenium per one hundred kilograms of sand are usually employed, and the amount should never exceed five grams per one hundred kilograms of sand used.

COLORING AGENTS.

The different types of glass that have been referred to may be produced in a large variety of different colors by the addition of a small quantity of one or more of certain chemical compounds, or elements, to the batch.   The same material does not produce the same color in all glasses, this varying with the composition of the glass and also with the conditions under which the glass is produced.

Colored glasses may be divided into two classes:—namely, those in which the color is introduced by a colored compound present in a state of solution in the glass, and those in which the color is due to the optical effect of minute particles held in suspension by the glass.   In the former case the intensity of the color is proportional to the concentration of the solution of the coloring material, while in the latter case the color depends upon the size and distribution of the particles.

The coloring agents commonly employed to produce violet, blue, green, yellow, and red in glass are taken up in the order named.

VIOLET.
Manganese Dioxide. MnO_2.

Manganese has already been referred to under the head of decolorizers.   It produces a range of colors from amethyst to violet, according to the composition of the glass.   The full color is only developed when the manganese is in the completely oxidized condition, and it can be altered or discharged by introducing reducing substances.   In a lime-potash glass, manganese gives an amethyst color, while in the case of lime-soda or a lead glass the color is reddish violet.

By adding manganese and iron together in considerable quantities, amber and brown glasses are produced. If the quantity is greater than the glass can dissolve the excess remains in suspension, producing black glass.

Manganese is usually added to the glass batch as the black manganese dioxide, which occurs in nature as the mineral pyrolusite. For the finer grades of glass refined manganese dioxide or manganese carbonate are sometimes used. For bottle glass cheaper grades of manganese ores are employed, but their analyses must be watched.

A little cobalt, in the form of the oxide, is sometimes added in connection with manganese to improve the violet color.

Nickel Oxide. NiO.

Nickel oxide has already been referred to under decolorizers. It exerts a powerful coloring influence on glass, but the color varies considerably with the composition of the glass and the state of oxidation of the nickel. Its successful use therefore requires a great deal of skill. Nickel produces an amethyst color in a lime-potash glass, a reddish-brown color in a lime soda glass, and a purple color in a lead glass. A little cobalt oxide is sometimes added with it to improve the violet color.

BLUE.

Cobalt Oxide. CoO.

Cobalt is one of the most powerful coloring agents in glass, and is the oxide commonly used in producing all varieties of blue glass. The blue of cobalt is very little affected by the composition of the glass or by the state of oxidation of the metal. With lime-potash and lime-soda glasses it yields a violet blue color, while with lead glass it gives a spectrum blue. Only a very little is necessary, 0.1% being sufficient to produce a strong blue, while even as low as 0.01% yields a pale blue. Cobalt is usually added to glass in the form of the oxide, CoO.

Copper Oxide. CuO.

When copper oxide is added to a lime potash glass, under oxidizing conditions, a pale blue color is produced in the glass by the formation of a cupric silicate, which is soluble in the glass. In the case of a lime soda glass, under similar conditions, the color is a greenish-blue.

GREEN.

Ferrous Oxide. FeO.

The effect of ferrous iron as a coloring agent has already been discussed under decolorizers. Ferrous iron colors a lime-potash glass a greenish-blue tint, a lime-soda glass a blueish-green, and a lead glass a yellowish-green. The depth of the color depends upon the amount

of iron present. Attention has been called to the fact that iron is present as an impurity, at least in minute quantities, in practically all glass batches, and that ordinary varieties of glass, such as bottle, window, and plate, owe their blueish-green tint to the presence of small amounts of ferrous iron in the glass, occurring undoubtedly in the form of a silicate which is soluble in the glass.

Copper Oxide. CuO.

Copper oxide, under oxidizing conditions, produces a green color in lead glasses by the formation of a cupric silicate which is soluble in the glass.

Chromium Oxide. Cr_2O_3.

Chromium is a very active coloring substance and is therefore used extensively. Chromium colors glass various depths and shades of green, the depth and shade depending upon the proportion of chromium used and the composition of the glass. In a lime-potash glass the resulting color is yellow-green, in a lime-soda glass a grass-green, and in a lead glass a reddish-green.

Chromium has the advantage over many other coloring agents in that it is relatively cheap and can be readily obtained and introduced into the glass in the form of pure compounds, whose coloring effect can be accurately anticipated. It has the further advantage that colors produced by it are little affected either by reducing or oxidizing conditions in the furnace, and only slightly by the length or temperature of the melting process. The rate of cooling does, however, have considerable influence on the color.

Chromium is only slightly soluble in glass and if added in amounts exceeding 4% or 5% the excess separates out on cooling producing an opaque, green glass. By careful manipulation it is possible to get the oxide to separate out in the form of crystalline flakes. The result is a translucent green glass filled with minute spangles, known as chomium aventurine.

Chromium is added to the glass batch either as the green oxide (Cr_2O_3), as potassium dichromate ($K_2Cr_2O_7$), as potassium chromate (K_2CrO_4), as a lead chromate ($PbCrO_4$), or as barium chromate ($BaCrO_4$). Of these potassium dichromate is the form most commonly employed. Chromic oxide itself is an extremely refractory body, and is, therefore, comparatively difficult to incorporate into a glass. On the other hand if the chromium is added in the form of potassium dichromate its solution in the glass is very much facilitated.

Uranium Oxide. UO_3.

Uranium produces a yellowish-green color in a lime-soda glass. While this is slightly fluorescent, it cannot compart in beauty with

the yellow fluorescent color developed by uranium in a lime-potash glass. Uranium may be added to the glass batch either as the oxide (UO_3), which is a yellowish-brown powder, or as sodium uranate ($Na_2UO_7 \cdot 3H_2O$), which has a yellowish orange color.

YELLOW COLOR.

Ferric Oxide. Fe_2O_3.

When iron is present in the ferric state it gives the glass a yellowish tint which is not as marked, however, as the green color produced by an equal amount of ferrous iron. In the the case of a lime-potash glass ferric iron gives a yellowish-green tint, in a lime-soda glass a greenish-yellow, and in a lead glass a yellow-green.

Sulphur.

Sulphur produces a greenish-yellow coloration in alkali glasses by combining with the alkali and lime to form sulphides. Sulphur must be kept out of lead glasses, as the formation of lead sulphide throws lead out of solution and renders the glass opaque.

Cerium Oxide. CeO_2.

Cerium oxide produces a yellow color in glass.

Uranium Oxide. UO_3.

Uranium produces a characteristic and beautiful yellow color in glass, which possesses a marked greenish fluorescence. This is especially true in the case of the lime-potash glasses. The fluorescence is not so marked in the case of lime-soda glasses, and is absent in the lead glass. Uranium may be added to the glass batch as the oxide (UO_3), or as sodium uranate ($Na_2UO_7 \cdot 3H_2O$). Sometimes it is added as uranyl-acetate ($UO_2(C_2H_3O_2)_{22}$) or uranyl-nitrate ($UO_2(NO_3)_2$).

Silver. Ag.

Silver under favorable conditions imparts an orange color to a lime-potash glass and a deep yellow to lime-soda and lead glasses. The color varies from light to dark according to the quantity used. By gradually increasing the amount a point is reached where opacity results. Repeated melting intensifies the color. The yellow color of silver is due to the colloidal suspension of fine particles of silver through the glass, which transmit yellow light. Silver may be introduced into the glass as the nitrate ($AgNO_3$), as the chloride ($AgCl$), or as the borate ($Ag_2B_4O_7$). When it is added in the form of silver chromate (Ag_2CrO_4) a beautiful greenish-yellow glass is obtained.

Silver is usually applied to the surface of the glass as a stain. It is readily absorbed by the glass and this is taken advantage of to

color sheet glass yellow by penetration. The glass is painted with one of the salts of silver and heated to about 400°C, causing it to absorb a certain amount of silver. When it is further heated to about 800°C the silver compound decomposes, and the silver goes into colloidal suspension producing a yellow color in the surface film of the glass. The temperature of combination and precipitation varies with the composition of the glass, lime-potash glass, low in silica, producing the richest colors.

RED COLOR.

Copper Oxide. CuO.

When copper oxide is added to glass under reducing conditions, and the glass is cooled slowly, or is exposed to repeated heating followed by slow cooling, an intense ruby coloration is produced. The copper is precipitated in the glass in colloidal suspension. Carbon or some other organic reducing agent is usually employed, but inorganic substances, such as stannous chloride ($SnCl_2$), stannous oxide (SnO), or metallic tin, are also used. It is a matter of considerable skill to obtain the proper division and suspension of the copper to produce the ruby color. If the particles become too large and unevenly distributed, a streaky, opaque red results, resembling sealing wax. By exceedingly slow cooling and under other favorable conditions the particles of suspended cooling material grow in size and appear as minute shimmering flakes, producing what is known as "aventurine."

The ruby color of copper is usually so intense that it can only be employed in very thin sheets by "flashing" it upon the surface of a colorless glass. This is accomplished by first taking a small gathering of ruby glass upon a pipe and then taking the remaining gatherings required from a pot of colorless glass. When such a composite gathering is blown into a cylinder, the ruby glass lies as a thin layer over the inner surface of the cylinder. Care must be taken that this layer is evenly distributed and of the right thickness to produce just the tint of ruby required. The chemical composition of the ruby glass and the colorless glass must also be such that the two glasses will have very nearly the same coefficient of thermal expansion, or internal strains will be set up in the glass which are apt to result in fracture.

Gold. Au.

Gold can be used for the production of brilliant ruby tints in the same manner as copper. Since gold has a greater tendency to return to the metallic state than copper, no reducing agents are necessary. The rate of cooling, however, must be carefully regulated. Rapidly cooled glass containing gold shows no special color, but when the glass is reheated and cooled slowly a rich, rose-ruby tint is developed.

It is easier to obtain this color with gold than with copper as there is not the danger of oxidation to contend with. Lighter shades of red may also be obtained so that "flashing" is not essential.

The gold is added to the glass by mixing gold chloride ($AuCl_3$) with sand and scattering it over the surface of the batch. A molecular solution of gold in the glass is obtained. When this is reheated and slowly cooled the gold particles become enlarged and a colloidal suspension of red gold in the glass results.

Selenium. Se.

Selenium produces a pale, rose-red color in glass. The intensity of the color depends upon the chemical composition of the glass and the duration and temperature of the melting process. The pink color of selenium is best developed in those glasses which contain barium as a base. Lime-soda glasses do not show it as well. The use of selenium as a decolorizer has already been referred to.

OPACIFIERS.

Under opacifiers are included those materials which when added to the glass both produce translucent, opal, alabaster or opaque white glasses. Opalesence is produced by bringing about a colloidal suspension of some suitable compound in the glass. If the particles are increased in size the glass becomes opaque. The following compounds are most frequently used for producing these types of glass.

Calcium Phosphate.• $Ca_3(PO_4)_2$.

Calcium phosphate when added to a glass batch in sufficient quantity produces a turbid white glass. In smaller amounts an opal glass is produced, which transmits a reddish light. The glass at first is colorless, the opalescent effect appearing only after the glass has been reheated.

Fluorine Preparations.

Certain fluorides when added to a glass bath produce opacity. Glass rendered opalescent by them does not transmit red light, as does an opalescent glass produced from bone ash (calcium phosphate) but is pure milk white. Aluminum fluoride is usually employed. It is introduced into the glass batch either as a mixture of the minerals fluorite (CaF_2) and orthoclase ($KAlSi_3O_8$), or as cryolite ($AlNa_3F_6$).

Tin Oxide. SnO_2.

Tin oxide in a fine suspended state, also produces opalescence in glass and in large quantities white opacity.

CHAPTER VI.

PREPARATION OF THE BATCH.

The necessary mixture of raw materials, which when melted together forms glass, is known as the batch. One of the primary essentials of a good glass batch is that it be well proportioned and thoroughly mixed. The exact composition varies considerably, even for the same kind of glass, depending upon a number of different factors, among which are the character of the raw materials employed, the kind of fuel used, and the style and construction of the furnace. The success of the operation, therefore, depends largely upon the skill and intelligence with which the factors are studied and applied. A good batch for one furnace and a certain set of materials often proves unsatisfactory when used for another type of furnace, or when the raw materials are procured from some other source. Recipes for glass batches which are derived from the practice in one section do not always give successful results in some other locality, where working conditions are somewhat different.

There is still considerable opportunity for improvement in connection with the preparation of glass batches. By keeping a better control of the chemical composition of the batch better results could be obtained in many cases. By making analyses from time to time of the raw materials going into the batch, the gaseous fuels employed, and the glass itself, information can be acquired which if rightly understood and applied would undoubtedly lead to the more uniform obtaining of good results. The composition of the raw materials should be watched in particular. Variation in the composition of any of these cannot but affect the resultant glass.

Composition of the Batch.

In the following tables the composition of several batches for each of the more common kinds of glass are given. They are calculated on the basis of 100 parts of sand.

Window Glass Batches.

	Ameri-can. (4)	Ameri-can. (4)	Ameri-can. (4)	Ameri-can. (4)	Ameri-can. (3)	Eng-lish. (1)	French. (4).
Sand,	100	100	160	100	100	100	100
Limestone,	26	38	40	34			25
Lime,					31¼		
Slaked lime,						53	
Soda ash,		4					
Salt cake,	44	40	42	43	27½	53	35
Carbon,	4	8	6	5	⅝	6	1½
Arsenic,	2	1	2	0.5			½

Window Glass Batches, Continued.

	French. (4)	French. (4)	German. (4)	German. (4)	German. (4)	German. (4)
Sand,	100	100	100	100	100	100
Limestone,	35	34	30	38	32	30
Lime,						
Slaked lime,						
Soda ash,						6
Salt cake,	40	42	35	45	45	35
Carbon,	2	2	12½	3	2	3
Arsenic,	1					

Plate Glass Batches.

	American. (4)	American. (4)	American. (4)	English. (1)	French. (5)	French. (5)	French. (5)
Sand,	100	100	100	100	100	100	100
Limestone,	24	24	38			7½	35
Lime,					14⅓		
Slaked lime,				13⅓			
Soda ash,	30	36		33⅓	33⅓	62½	30
Salt cake,			40				
Carbon,	1	¾	4				
Arsenic,		1	2			⅕	½
Manganese dioxide,					⅛	¼	¼

Plate Glass Batches, Continued.

	French. (5)	French. (5)	German. (4)	German. (4)	German. (4)	German. (2)	German. (2)
Sand,	100	100	100	100	100	100	100
Limestone,	14½	40	38			34½	37
Lime,							
Slaked lime,				20	14		
Soda ash,	34	35		35	33	17⅓	
Salt cake,			38				37
Carbon,			2½				2½
Arsenic,		⅕	½				
Maganese dioxide,	¼	¼					

Lime Flint Batches.

	American. (3)	Belgian. (4)	(4)	(4)
Sand,	100	100	100	100
Limestone,		24	36	36
Lime,	10			
Soda ash,	33⅓		30	33
Salt cake,		32		
Saltpetre,			1½	
Chili saltpetre,	13⅓			
Carbon,		2½		
Arsenic,				2
Manganese dioxide,			½	1

Bottle Glass Batches.

	American. (3)	American. (4)	American. (4)	American. (4)	American. (4)
Sand,	100	100	100	100	100
Limestone,	30	36	32	34	36
Soda ash,	27½	36	35		
Salt cake,				38	42
Salt,	3⅓				
Carbon,				5	8

Lead Flint Batches.

	American. (4)	American. (4)	American. (3)	English. (5)	English. (5)	English. (5)	English. (5)
Sand,	100	100	100	100	100	100	100
Potash,	36	34	33⅓	33⅓	20	36	26
Nitre,	5	6	10				3⅓
Red lead,	40	48	40	66⅔	60	55	70
Borax,	⅓						4
Arsenic,	½	⅛	1/10			1	
Manganese dioxide,	¼	1/16	1/10				
Antimony,		1/50					

Lead Flint Batches, Continued.

	English. (5)	English. (1)	English. (1)	French. (4)	French. (4)	French. (4)	German. (4)
Sand,	100	100	100	100	100	100	100
Potash,	33⅓	33⅓	50	31	33	30	35
Nitre,	16⅔					⅖	
Red lead,	42	63⅔	100	67	67	67	67
Borax,							
Arsenic,					⅔		⅓
Manganese dioxide,	½				½	1/40	⅕
Antimony,							

Lead Flint Batches, Continued.

	German. (4)	German. (4)	German. (4)
Sand,	100	100	100
Potash,	28	30	34
Nitre,	6	3	16
Red lead,	67	63	42
Borax,			
Arsenic,	¼	⅓	
Manganese,	⅙	⅕	½
Antimony,			

1. The Commoner and Glassworker, Vol. 21, No. 11, 1899. Quoting from English Pottery Gaette.
2. Die Glas-fabrikation, 2nd edition, Raim and Gerner, Vienna, 1897, p. 295.
3. Report on the Manufacture of Glarss, by Jos. D. Weeks, 1883. Census Report.
4. Glass, Robert Linton. The Mineral Industry for 1899, Vol. 8, pp. 234-263.
5. Glass. Dictionary of Applied Chemistry, by Sir Edward Thorpe, Vol. 2, 1912, pp. 719-739.

At the time the batch consisting of the well mixed raw materials is charged into the furnace, some cullet or broken glass is also admitted. This should preferably be crushed to the size of about one inch in diameter, but in practice in the case of the cheaper grades of glass this is seldom done. For the higher grades it becomes necessary to do so, or the glass lacks homogeneity, as large pieces of cullet do not diffuse readily through the rest of the melt. In the case of such glasses it is also necessary to have the composition of the cullet similar to that of the glass produced, and the cullet should be clean.

Cullet fuses at a much lower temperature than the raw batch, and, therefore, assists in the melting. Its presence also holds up and makes the mass more open, thereby allowing the ready escape of the gases during the early stages of the fusion. An excess of cullet, however, produces a brittle or weak glass. Just how much may be added without injury to the glass is still a disputed question. Some recommend the addition of a weight of cullet equal to the weight of the sand used, while others think that as low as one-third that amount is nearer the right figure.

Methods of Calculating Glass Batches.

To calculate the composition of the glass from that of the batch.

Batch.

Sand,	100	pounds
Limestone,	35	pounds
Soda Ash,	32	pounds
Salt Cake,	6	pounds
Coal,	0.4	pounds

Analysis of Sand.		Analysis of Limestone.	
SiO_2,	99.7 %	SiO_2,	.92 %
Al_2O_3,	.24 %	Al_2O_3,	1.00 %
Fe_2O_3,	.026%	Fe_2O_3,	.10 %
	99.966%	$CaCO_3$,	95.20 %
		$MgCO_3$,	2.40 %
			99.62 %

Analysis of Soda Ash.		Analysis of Salt Cake.	
Na_2CO_3,	98.00 %	Na_2SO_4,	97.00 %

Assume a volatization loss of 5% of the sodium in the furnace. This is a somewhat higher figure than usually occurs in practice.

Molecular weight of Na_2O,	62.1	
CO_2,	44.	
Na_2CO_3,	106.1	
Molecular weight of Na_2O,	62.1	
SO_3,	80.06	
Na_2SO_4,	142.16	
Molecular weight of CaO,	56.	
CO_2,	44.	
$CaCO_3$,	100.	
Molecular weight of MgO,	40.36	
CO_2,	44.00	
$MgCO_3$,	84.36	

100 x .997 = 99.7 pounds SiO_2 in the sand.
100 x .0024 = 0.24 pounds Al_2O_3 in the sand.
100 x .00026= 0.026 pounds Fe_2O_3 in the sand.

$$35 \text{ x } .952 \text{ x } \frac{56}{100} = 18.659 \text{ pounds CaO in the Limestone.}$$

$$35 \text{ x } .024 \text{ x } \frac{40.36}{84.36} = 0.402 \text{ pounds of MgO in the limestone.}$$

35 x .0092 = 0.322 pounds of SiO_2 in the limestone.
35 x .01 = 0.35 pounds of Al_2O_3 in the limestone.
35 x .001 = 0.035 pounds of Fe_2O_3 in the limestone.

$$32 \text{ x } .98 \text{ x } \frac{62.1}{106.1} = 18.35 \text{ pounds Na}_2\text{O in the Soda Ash.}$$

$$6 \text{ x } .97 \text{ x } \frac{62.1}{142.16} = 2.54 \text{ pounds of Na}_2\text{O in the Salt Cake.}$$

18.35 + 2.54 = 20.89 pounds of Na_2O.

20.89 — 5% (volatization loss) = 19.85 popnds of Na_2O for the glass.

99.7 pounds SiO_2 in sand.	0.24 pounds Al_2O_3 in the sand.
.322 pounds SiO_2 in limestone.	0.35 pounds Al_2O_3 in the limestone.
100.022 pounds of SiO_2 for the glass.	0.59 pounds of Al_2O_3 for the glass.

0.026 pounds Fe_2O_3 in sand.
0.035 pounds Fe_2O_3 in limestone.

0.061 pounds Fe_2O_3 for the glass.

100.022 pounds SiO_2	Caleulating on the basis of 100%.	
.59 pounds Al_2O_3	SiO_2, ------------------------------	71.6
.061 pounds Fe_2O_3	Al_2O_3, ------------------------------	.4
.402 pounds MgO	Fe_2O_3, ------------------------------	.05
18.659 pounds CaO	MgO, ------------------------------	.3
19.85 pounds Na_2O	CaO, ------------------------------	13.4
	Na_2O, ------------------------------	14.2
139.584 pounds.		99.95

To Caleulate the eomposition of the Bateh from that of the Glass.
Analysis of the Glass.

SiO_2, ---	72.68
Al_2O_3, Fe_2O_3, ---	1.06
MgO, --	.26
CaO, --	12.76
Na_2O, ---	13.24
	100.00

The same sand, limestone, and salt cake as in the previous calcu-
lation are to be used. No soda ash is to be employed in this case.
A volatization loss in the furnace of 5% for sodium is assumed.

Start with 100 pounds of glass.
100 x .1276 = 12.76 pounds of CaO in the glass.

$$12.76 \text{ x } \frac{100}{56} \text{ x } \frac{100}{95.2} = 23.93 \text{ pounds of limestone required to furnish the CaO.}$$

100 x .7268 = 72.68 pounds of SiO_2 in the glass.
23.93 x .0092 = 0.22 pounds of SiO_2 in the limestone.
72.68 — 0.22 = 72.46 pounds of SiO_2 to eome from the sand.

$$7\text{°}.46 \text{ x } \frac{100}{99.7} = 72.68 \text{ pounds of sand required.}$$

100 x .1324 = 13.24 pounds of Na_2O in the glass.

$$13.24 \text{ x } \frac{100}{95} = 13.94 \text{ pounds of Na}_2\text{O after volatization loss is added.}$$

$$13.94 \times \frac{142.16}{62.1} \times \frac{100}{97} = 32.9 \text{ pounds of } Na_2SO_4 \text{ (Salt Cake)}.$$

$23.93 \times .01 = 0.24$ pounds of Al_2O_3 in the limestone.
$72.68 \times .0024 = 0.17$ pounds of Al_2O_3 in the sand.
_____
0.41 pounds of Al_2O_3 in glass resulting from this batch.

$23.93 \times .001 = 0.02$ pounds of Fe_2O_3 in limestone.
$72.68 \times .00026 = 0.02$ pounds of Fe_2O_3 in sand.
_____
0.04 pounds of Fe_2O_3 in 100 pounds of glass resulting from this batch.

$0.41 + 0.04 = 0.45$ pounds of Al_2O_3 and Fe_2O_3. This amount is 0.61% less than that of the glass for which the batch is being calculated. The difference is due to using a sand and limestone of slightly different composition from that used in the original glass.

$$23.93 \times .024 \times \frac{40.36}{84.36} = 0.27 \text{ pounds of } MgO \text{ in 100 pounds of glass resulting}$$
from this batch. This is the same as that of the glass for which the batch is being calculated.

Resulting Batch.		Calculating on the basis of 100 pounds of sand.		
72.68 pounds of sand.		Sand,	100	pounds
23.91 pounds of limestone.		Limestone,	33	pounds
32.90 pounds of Salt Cake.		Salt Cake,	45.4	pounds
$45.4 \times .065 = 2.95$ pounds coal.		Coal,	3	pounds

To Calculate the Composition of the Batch from the Molecular Relationship of the Lime, Soda and Silica.

Tscheuschner has derived the following formula for a normal glass:

$$xR^1{}_2O \ . \ yR''O \ . \ 3 \left(\frac{x_2}{y} + y\right) SiO_2.$$

$xR^1{}_2$ represents the sum of the molecular ratios of the Na_2O and K_2O.
yR'' represents the sum of the molecular ratios of the CaO, MgO, BaO, PbO, ZnO and Fe_2O_3.
For a lime soda glass, according to Dralle, when y is made equal to 1, x can vary between .5 and 1.0.
Assume therefore a case where $x = 0.9$ and $y = 1$.

Then $3 \left(\dfrac{x^2}{y} + y\right) = 5.4$.

The same sand, limestone and salt cake as in the previous calculation are to be used. A 5% loss of sodium in the furnace is assumed.
The limestone contains 95.20% $CaCO_3$ and 2.40% $MgCO_3$.

$$2.40 \ MgCO_3 \text{ are equivalent to } 2.4 \times \frac{100}{84.36} = 2.84\% \ CaCO_3.$$

$95.20 + 2.84 = 98.04\%$ limestone.
To get 1 molecule of CaO requires 1 molecule of $CaCo_3$.
1 pound molecule of $CaCO_3$ weighs 100 pounds.

$$100 \times \frac{100}{98.04} = 102 \text{ pounds of limestone.}$$

$102 \times .0092 = 0.94$ pounds of SiO_2 in limestone.
Molecular weight of SiO_2 is 60.4.
5.4 molecules of SiO_2 are required.
$5.4 \times 60.4 = 326.16$ pounds of SiO_2.
$326.16 - 0.94 = 325.22$ pounds of SiO_2 to be derived from the sand.

$$325.22 \times \frac{100}{99.7} = 326.2 \text{ pounds of sand.}$$

0.9 molecules of Na_2O are required.
This will require 0.9 molecules of Na_2SO_4.
$Na_2SO_4 = 97\%$ pure and there is a 5% volatilization loss.

$$0.9 \times \frac{100}{95} \times \frac{100}{97} \times 142.16 = 138.8 \text{ pounds of salt cake.}$$

Batch.		Calculating on the basis of 100 pounds of sand.		
Sand,	326.2 pounds			
Limestone,	102.0 pounds	Sand,	100	pounds
Salt Cake,	138.8 pounds	Limestone,	31.3	pounds
$2.6 \times .065 = 2,769$ pounds of coal.		Salt Cake,	42.6	pounds
		Coal,	2.75	pounds

The alumina and ferric oxides were neglected in the above calculation, as they are present in only small amounts.

Mixing the Batch.

It is absolutely essential that the batch be thoroughly mixed before it is charged into the furnace. A special room which can be kept clean is usually provided for this purpose. In it are storage bins for the various raw materials, and scales for weighing these out. Materials which are used only in very small quantities are weighed out on special balances.

In small factories the mixing is done by hand in large wooden boxes or bins. The various ingredients of each batch are turned over a number of times with shovels, or hoes, and are then usually passed through a sieve of suitable mesh. In the larger factories, however, machinery is employed for this purpose. Plate XXII shows types of glass batch mixers manufactured by the F. L. Smith Company of Milwaukee, Wisconsin, which have found a rather wide spread usage in the glass industry. This type of mixer consists of a revolving, double conical shaped, drum, inside of which are placed blades riveted at an angle to the central axis. These blades are arranged in V shaped sets, to pick up, spread out, and turn over the batch. The material is charged into the drum at one end through a feed chute or batch hopper, and is discharged at the other end by tilting the mixer while running.
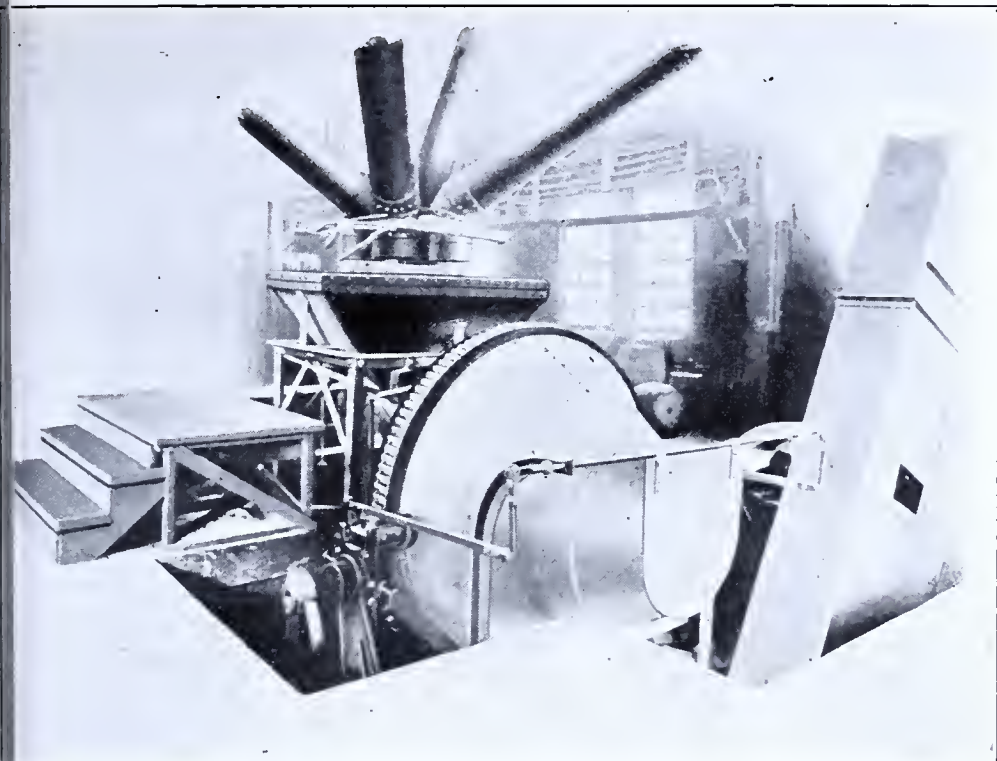
Fig. 1. One ton Smith Glass Batch Mixer, arranged for mechanical handling of batch to and from the mixer.
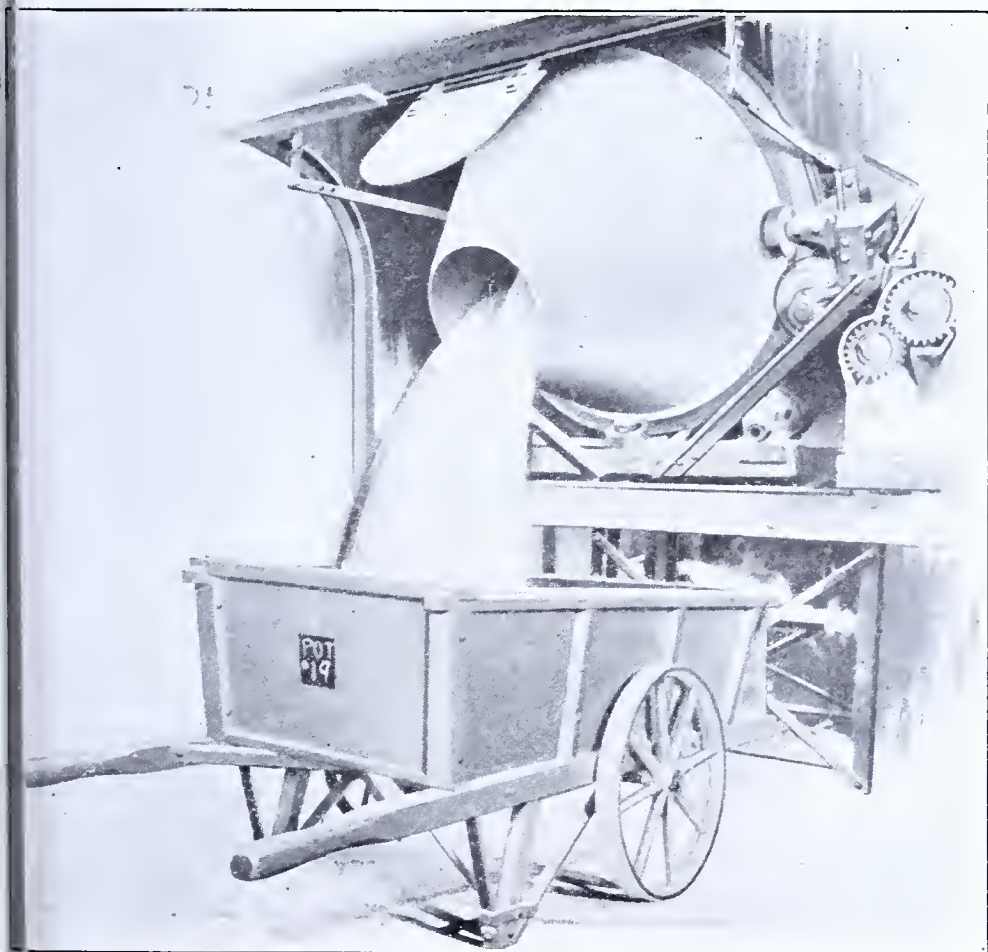
Fig. 2. No. 117 Smith Glass Batch Mixer discharging.

CHAPTER VII.

FUEL.

In the early days of the glass industry furnaces were fired with solid fuel, such as coal and wood. Later, however, with the discovery of large gas and oil pools in various parts of the United States, especially in Pennsylvania and West Virginia, these furnaces were almost entirely replaced with ones in which gaseous fuel is employed. This type of fuel has many advantages over solid fuels, especially in the manufacture of glass. There is no ash or dust to contend with, and the burning is easy to control, so that furnace temperatures can be easily regulated. This is a factor of great importance in glass manufacture.

Natural gas is the best fuel of this type on account of its high calorific value. The great glass manufacturing centers of the United States have, therefore, sprung up where there has been an abundant supply of natural gas available. In recent years, however, with the gradual exhaustion of the older gas fields and the constantly increasing demand for gasseous fuel by various industries and domestic uses with the consequent increase in the price of natural gas, there has been a growing tendency to replace natural gas by producer gas made from coal.

Natural Gas.

Natural gas is colorless and practically oderless. It burns readily with a luminous flame and is the most valuable of the gaseous fuels from a heating point of view. In composition it consists chiefly of methane or marsh gas (CH_4), but higher members of the paraffin series of hydrocarbons, such as ethane (C_2H_6) and olefine (C_2H_4) are also frequently present in small quantities, as are carbon monoxide (CO), and carbon dioxide (CO_2) and varying amounts of nitrogen, and oxygen.

Analysis of Natural and Producer Gas[26].

	Average Pennsylvania and West Virginia.	Average Ohio and Indiana.	Average Kansas.	Average producer gas from bituminous coal.
Marsh gas (CH₄),	80.85	93.60	93.65	2.05
Other hydrocarbons,	14.00	.30	.25	.04
Nitrogen,	4.60	3.60	4.80	56.26
Carbon dioxide,	.05	.20	.30	2.60
Carbon monoxide,	.40	.50	1.00	27.00
Hydrogen,	.10	1.50	.00	12.00
Hydrogen sulphide,	.00	.15	.00	.00
Oxygen,	trace.	.15	.00	.05
	100.00	100.00	100.00	100.00
British thermal units per 1,000 cubic feet,	1,145,000	1,095,000	1,100,000	155,000

26. U. S. Geological Survey. Mineral Resources of the U. S. 1905, p. 807.

One British thermal unit indicates the heat necessary to raise one pound of water at 39°F one degree.

Oil and gas are, with few exceptions, always found in sedimentary rocks.   There is usually, at least, a little gas found associated with oil, but at times the gas occurs alone.   The two may occur in separate beds, or in different parts of the same bed, having accumulated in the pore space of the rocks, or in joint planes, or other cavities. The bed containing the oil or gas is known as the oil or gas rock, or sand.   Usually this is a porous sandstone of varying coarseness, but occasionally porous limestones or fractured shales act as reservoirs. The portion of the formation which contains the oil or gas is known as the oil or gas pool.   There may be several pools in one district, and likewise several formations lying at different levels that contain oil and gas.   The thickness of the producing beds may be anywhere up to seventy-five or one hundred feet, or even more.   The depth of the producing formation below the surface also varies greatly.

Oil and gas are usually found under pressure, so that as soon as the stratum containing them is penetrated by the drill they rise to the surface.   This pressure often amounts to several hundred pounds per square inch when a field is first opened up, but gradually diminishes as more wells are drilled and the oil and gas are extracted. The yield of different wells and pools varies greatly.

The structure of the rocks usually determines the position of the pools in any particular district, the oil and gas being found in the highest portions of the productive beds, associated with any arch like structure, or anticlines, that may be present.   Other types of structure, however, may also determine the position of the pools, and whether the oil and gas sands are saturated with water is another factor which influences their location.
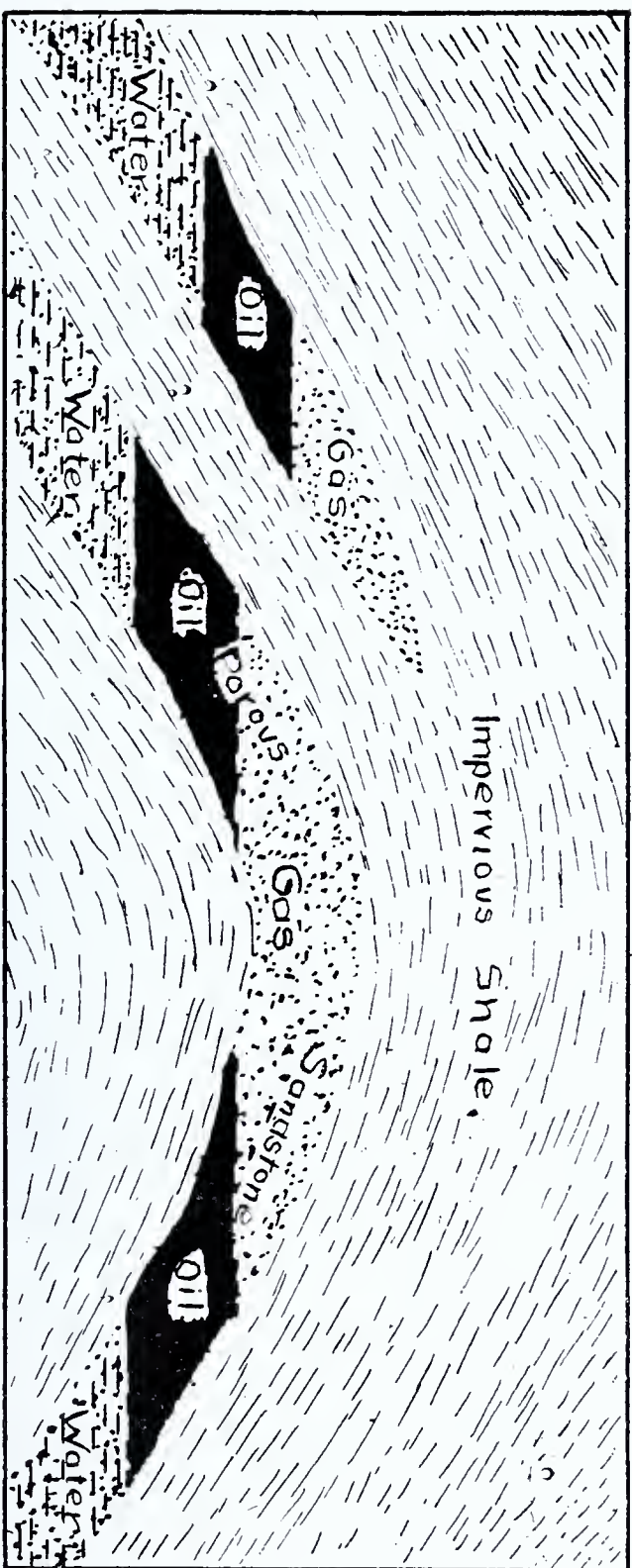
PLATE XXIII.

Diagram showing how gas, oil, and water may occur in the same sand.

Gas   Oil
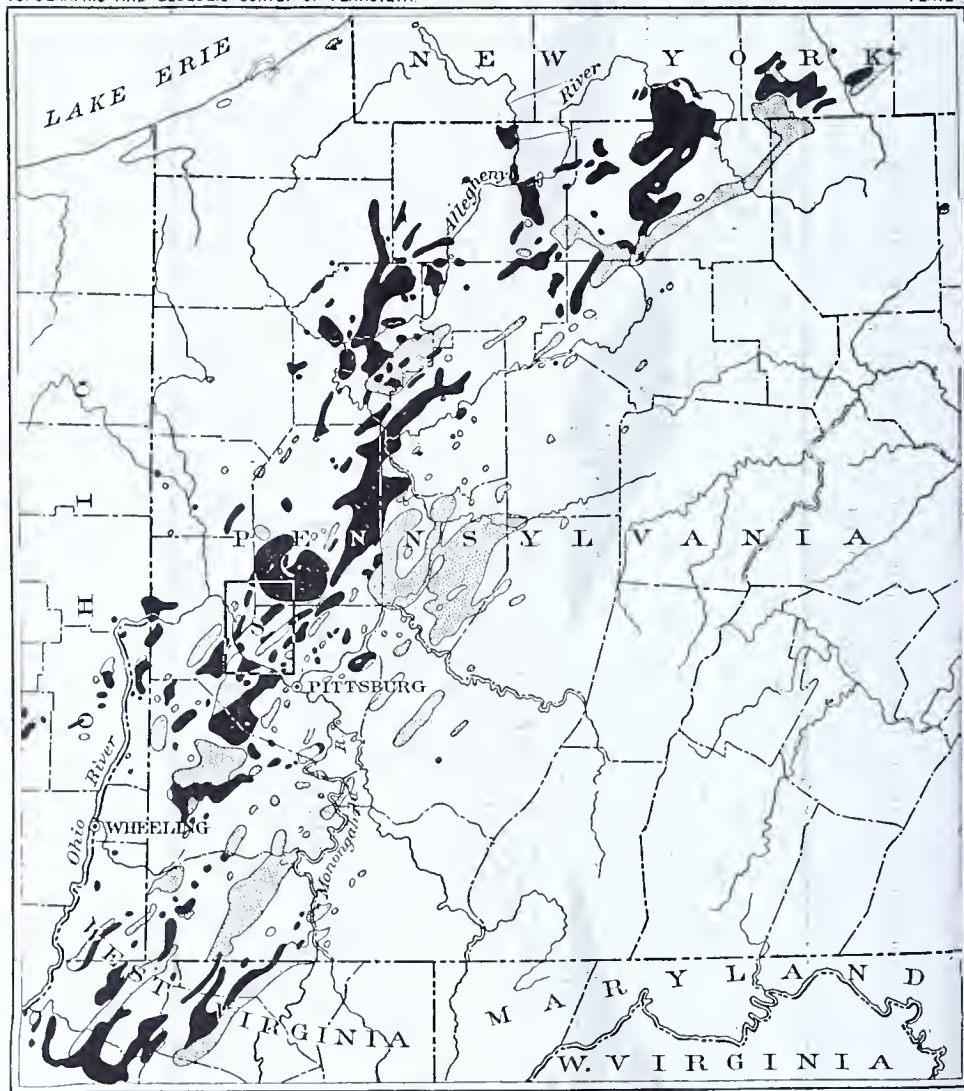
MAP SHOWING DISTRIBUTION OF OIL AND GAS FIELDS IN
WESTERN PENNSYLVANIA AND ADJACENT TERRITORY

PLATE XXIV.

It is now quite generally held by geologists that oil and gas have been derived from organic remains, either animal or plant, which were buried in the sedimentary rocks at the time of their deposition. By a slow process of decomposition the hydrocarbon compounds have been evolved, and accumulated in the porous portions of the formations in which they were buried.

There are certain requisites necessary for the storage and accumulation of natural gas. First, there must have been deposited with the sediments in which the gas occurs sufficient organic material to later give rise to the hydrocarbon compounds constituting gas. Second, there must be an open, porous, or cellular structure present in some of the beds in which the gas evolved from the decomposition of the organic material buried in the sediments can accumulate. Third, it is necessary to have this open structure capped by a clay or shale that will close up the reservoir and adjust itself to the vents caused by flexures due to later disturbances in the rocks, produced by earth movements, and thus prevent the escape of the gas. Fourth, there must be sufficient dip or relief in the gas holding stratum, that the gas can accumulate in the domes of the arches and the flanks of the elevations, and thus become separated from the petroleum and salt water with which it is usually associated. Plate XXIII illustrates two sets of conditions under which gas may accumulate.

In Pennsylvania the requisite conditions favorable for the occurance and accumulation of oil and gas are found in the western portion of the State. Natural gas pools are thickly scattered over the area west of an imaginary line drawn from the northwest corner of Potter County to the southeast corner of Green County. All of the counties in this part of the State, which comprise about one-third of its entire area, produce more or less natural gas. Plate XXIV shows the distribution of the oil and gas fields in western Pennsylvania and adjacent territory.

The gas is obtained from a large number of different sandstone layers or sands in this area. In the northwestern portion of the State the Kane, Elk, (Waugh and Porter), Bradford, Cherry Grove. Speechley, Tiona, Warren Second, Warren First, and Elizabeth of the Devonian system are the productive horizons; in the central western part of the producing area, the Gordon, Bowlder, and 30-foot of the Devonian (?) and the 50-foot, Gantz, and Berea (Butler county sand) of the Mississippian are productive, while in southwestern Pennsylvania, the Fifth, Fourth, Gordon, Bowlder, 30-foot, 50-foot, Gantz, Murrysville, Berea, Big Injun and Maxton sands, and the Homewood and Mahoning sandstones, of the Devonian, Mississippian and Pennsylvania, are the gas sands.

The following table gives the value of the natural gas produced and consumed in Pennsylvania between the years 1900 and 1914, as

taken from the reports of the United States Geological Survey on Mineral Resources. The quantities given are in units of one thousand cubic feet and the average price per thousand cubic feet for the same period is also given. The accompanying diagram, plates XXV and XXVI illustrate the increasing tendency of the consumption to exceed the production, and the gradual increase in cost of the natural gas on this account and also on account of the gradual diminution in yield of the gas fields.

Natural Gas Produced and Consumed in Pennsylvania from 1900 to 1914. (Compiled from Natural Resources Reports of U. S. Geological Survey.)

Year.	Production in M. cu. ft.	Average price per M. cu. ft. in cents.	Value of production.	Consumption in M. cu. ft.	Average price per M. cu. ft. in cents.	Value of consumption.
1900,			$10,215,412			$9,812,615
1901,			12,688.161			11,785,996
1902,			14,352,183			13,942,783
1903,			16.182,834			16,060,196
1904,			18,139,914			17,205,804
1905,			19,197,336			19,237,218
1906,	138,161,385	13.4	18,558,245	162,095,173	13.0	21,085,077
1907,	135,516,015	13.9	18,844,156	161,541,179	13.9	22,917,547
1908,	130,476,237	14.64	19,104,944	147,790,097	13.99	20,678,161
1909,	127,697,104	16.03	20,475,207	163,656,145	13.22	21,639,102
1910,	126,833,729	16.60	21,057,211	168,875,559	14.17	23,934,691
1911,	108,869,296	17.01	18,520,796	159,104,376	15.05	23,940,001
1912,	112,149,855	16.53	18,539,672	173,659,003	15.25	26,486,302
1913,	118,869,269	18.25	21,695,845	177,463,230	16.18	28,709,565
1914,	108,494,387	18.80	20,401,295	164,834,542	17.25	28,439,324

According to statistics collected by the Topographic and Geologic Survey of Pennsylvania in co-operation with the United States Geological Survey, of its own production of natural gas in 1914 Pennsylvania consumed 95,889,861 M. cubic feet, the remaining 12,604,526 M. cubic feet, valued at $3,576,605 being marketed in New York, West Virginia and Ohio. Of its enormous total consumption, 68,944,681 M. cubic feet, valued at $11,614,634 was piped into the State from adjoining states, almost entirely from West Virginia.

The greatest prospect for future development of natural gas in Pennsylvania lies in drilling to deeper sands. At present it no longer seems likely that new gas fields of importance will be found in the State, but a number of old gas fields threatened with extinction because of the exhaustion of the gas in the producing sands, have in recent years been rejuvenated by drilling to deeper sands, and further development along this line may be looked for.

Producer Gas.

Producer gas is a combustible mixture of several simple and compound gases, the chief ones of which are hydrogen, carbon monoxide,

30,000,000

25,000,000

Value of Consumption.

20,000,000

Value of Production.

15,000,000

10,000,000

5,000,000

2,500,000
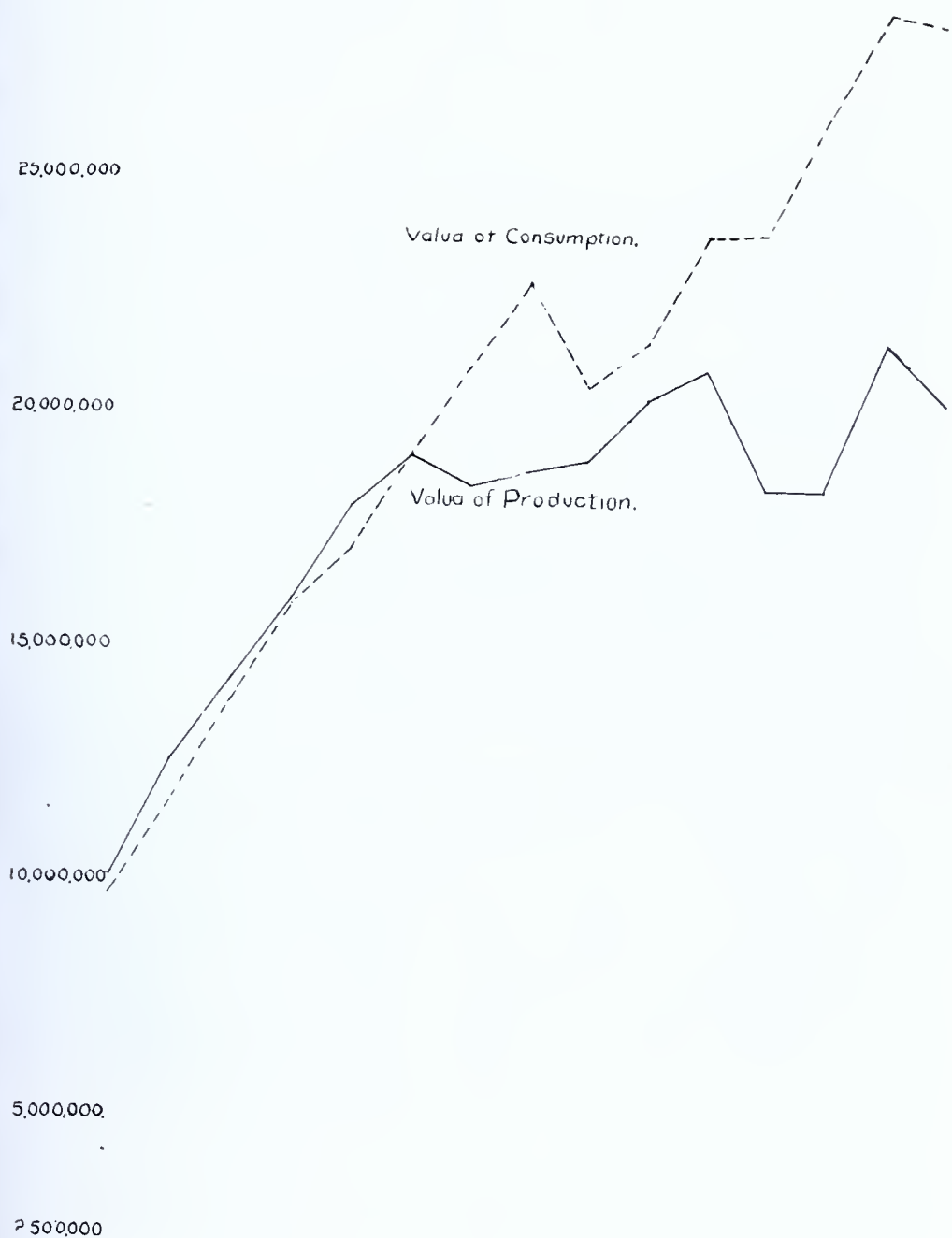
1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914

PLATE XXV.

Diagram showing the value of natural gas produced and consumed in Pennsylvania, during the period 1900 to 1914.

180,000,000   M Cu. Fr.

Consumption in M Cu. Ft.

160,000,000

140,000,000

Production in M Cu. Ft.

120,000,000

100,000,000

80 000.0

60,000,000

40,000,000

20,000,000

1906   1907   1908   1909   1910   1911   1912   1913   1914.
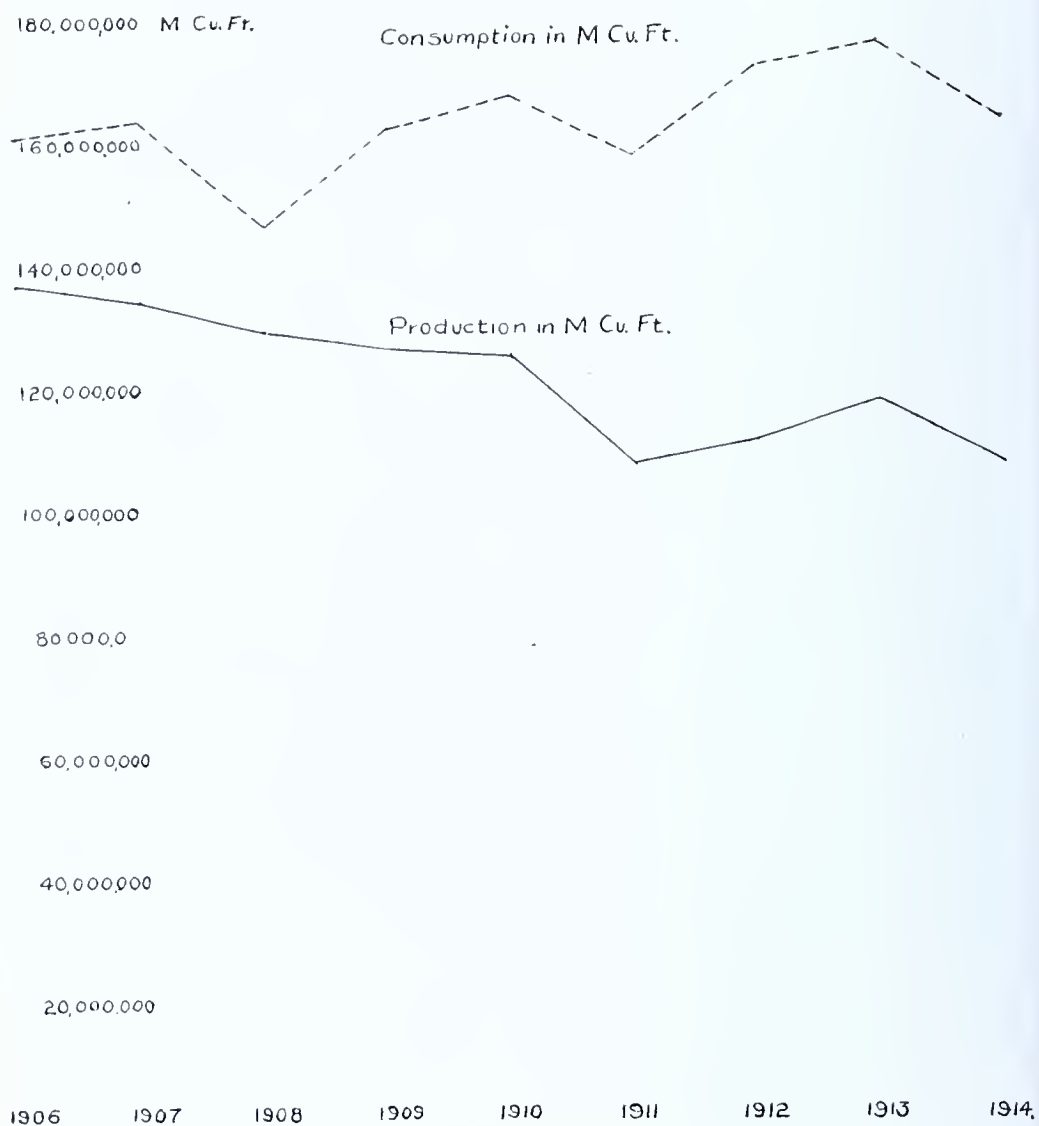
PLATE XXVI.

Diagram showing the amount of natural gas produced and consumed in
Pennsylvania during the period 1906 to 1914.

Green Coal
Distillation
Reduction
Combustion
Ash
Gas
Air & Steam
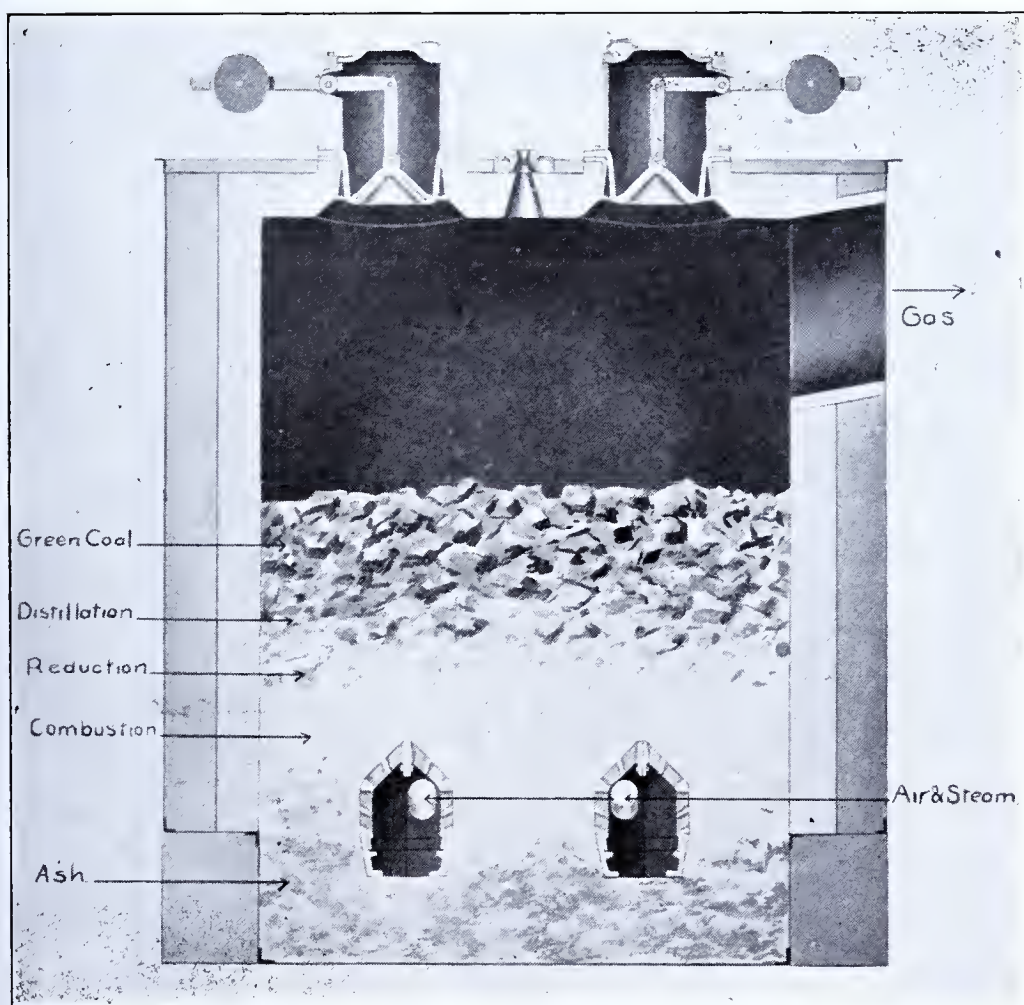
PLATE XXVII.

Cross section of Bradley Gas Producer, showing grates, two blowers, and dividing plates.

carbon dioxide, and nitrogen. It is manufactured by means of drawing by natural draft, or a fan or blower, air through a fuel bed of certain thickness confined in a fire brick lined steel shell, known as a producer. Some steam is also admitted in the process. Plate XXVII illustrates one type of gas producer. The entering air combines with the carbon of the bottom layer of fuel, which has been heated to incandescence, and carbon dioxide is formed ($C+O_2=CO_2$). This is a gaseous, non combustible product of complete combustion. It passes up through the higher layers of fuel and is reduced to carbon monoxide ($C+CO_2=2CO$). This is a combustible gas, and is one of the principle constituents of all producer gas. A minimum temperature of 1000°C is necessary for a perfect reduction of the carbon monoxide, although a partial reduction takes place at temperatures even as low as 450°C.

Carbon monoxide has a comparatively low heating value. It has been found that by blowing a mixture of steam and air, instead of pure air, through the fuel bed, a gas of much higher thermal value is obtained. When the steam reacts with the incandescent fuel it is decomposed, and carbon monoxide and hydrogen are formed ($C+H_2O=CO+H_2$). The hydrogen has a much higher calorific power than the carbon monoxide. Considerable nitrogen is added to the gas from the air passed through the fuel, and some of the carbon dioxide always remains undecomposed.

The following analyses, taken from Bulletin No. 13, United States Bureau of Mines, page 14, illustrate the composition of producer gas made in the same plant from two types of fuel. The analysis of natural gas quoted is taken from Power Gas and Gas Producers by J. C. Miller, page 35.

Analyses of Producer Gas.

	Gas from Montana lignite.	Gas from Pennsylvania bituminous coal.	Natural gas from the Pittsburgh district.
Hydrogen,	16.6	12.5	3.6
Carbon monoxide,	14.2	20.7	0.0
Methane,	2.9	2.5	92.0
Ethylene,	0.6	0.0	3.0
Oxygen,	0.2	0.0	0.0
Carbon dioxide,	13.2	8.7	0.0
Nitrogen,	52.9	55.6	2.0
	100.0	100.0	100.0
British thermal units per cu. ft.,	147.5	140.6	978.0

The composition of producer gas varies greatly, depending upon a large number of different factors, such as the type of the producer

used and the method and skill of operating it, the uniformity and reg-
ulation of the air and steam supply, the kind and quality of fuel used
and the depth of the fuel bed, and its distribution and uniformity.
The heat value of a producer gas is determined by the relative pro-
portions of hydrogen and carbon monoxide which are present in the
gas. The methane and ethylene are also combustible gases and pro-
duce heat. The nitrogen, carbon dioxide, and oxygen, on the other
hand being non combustible add nothing to the heat value, but act
as dilutents.

As has been already stated a temperature of not less than 1000°C
is required for the complete formation of carbon monoxide. Tempera-
tures higher than this, however, are not desirable, as they result in
a rapid destruction of the fire brick lining and in the formation of
slag from some of the ash, which is difficult to remove from the types
of producers in common use today. The temperature at which the
formation of slag gives trouble depends upon the composition of the
ash.

In order to reduce the fuel bed temperature, which otherwise might
become too high for successful commercial operation, especially when
bituminous coal is employed, water in the form of steam is added
to the gassifying air. This not only lowers the temperature but
increases the thermal value of the gas. Its decomposition to hydro-
gen, with the formation of carbon monoxide, has already been referred
to in a previous paragraph. This reaction consumes considerable
heat, which results in the lowering of the temperature of the fuel bed.
The reaction is also most complete at a temperature of about 1000°C.
At lower temperatures more and more carbon dioxide is produced,
and some of the water remains unchanged, and thus increases the
moisture content of the gas. This moisture in the gas if present
at the time of combustion consumes heat, and, therefore, lowers the
heating value of the gas. Care must, therefore, be exercised in using
steam to prevent the chilling of the fuel bed to such a point that the
necessary decomposition of the steam cannot take place. The amount
of steam that can be used to advantage, therefore, is comparatively
small. In the case of bituminous coal Nagel gives it at from 150 to
200 grams of water per cubic meter of air introduced.

In the upper portions of the fuel bed, especially when bituminous
coal is used, considerable volatile matter as well as some tarry ma-
terials are distilled from the fresh coal by the heat of the gases which
rise up through it. With bituminous fuels, therefore, too high a fuel
layer is not to be used, as this causes an increased formation of the
tar and soot, because the moisture and volatile matter will have time
to escape from the higher zones before the material reaches the in-
candescent zone of reduction. For three-fourths inch bituminous
coal about twenty-two inches is the proper height, according to Nagel,

PLATE XXVIII.
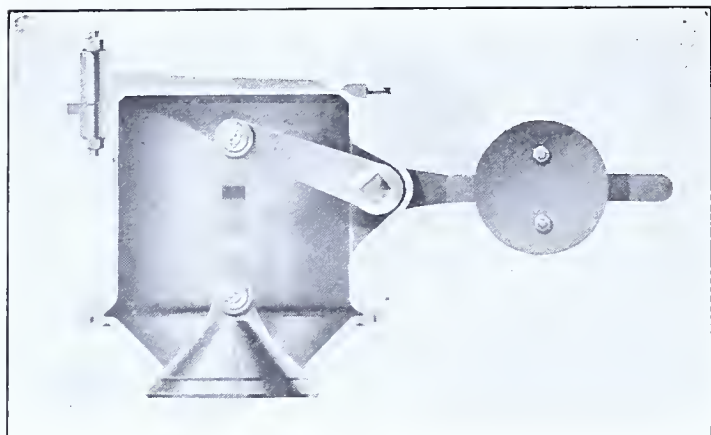
Fig. 1. Coal hopper for charging gas producers.
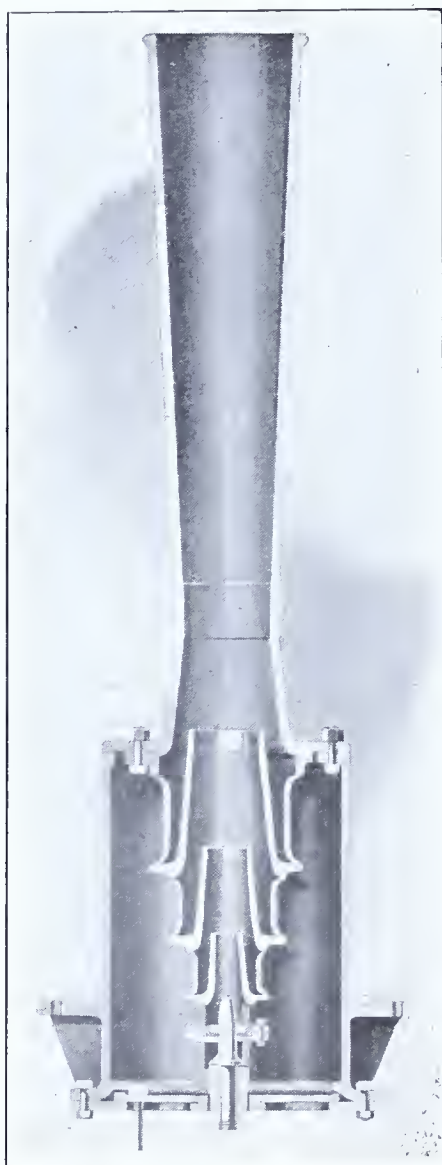
Fig. 2. Steam jet blower.

while for run of mine sixty to eighty inches is not too much. The higher the temperature of the upper layers the less tar will be produced, and the more hydrogen and methane will be found in the gas. The two latter components increase the thermal efficiency of the gas, while the tar is an undesirable impurity. It has to be removed where the gas is to be used in gas engines, but when it is used for fuel, this is not generally done.

The simplest type of gas producer consists of a vertical shaft built of fire brick and surrounded by an iron shell. The top is sometimes made of an arch of fire brick, but frequently it is only provided with water cooled covers made of iron. It is furnished with hoppers for charging fresh fuel. The shaft is usually circular, with vertical walls. The fuel moves downward in this shaft while the air and gas travel upwards. The gas formed passes up through the green fuel, carrying along water and volatile matter, and is led off through a large pipe at the side of the shaft, near the top.

Poke holes are generally placed in the cover and side walls that the layers of fuel may be stirred up from time to time and any clinkers which may tend to form broken up. The charging of fresh fuel is generally done through a bell hopper in the cover of the producer (See Plate XXVIII, Figure 1). In these hoppers the fuel is first placed in an upper hopper space, separated from the producer proper by an air tight bell. Then the upper door of the hopper is closed and the bell opened, allowing the change to run ito the producer. In this type of device the charging is intermittent. Various devices for continuous charging have been tried. One of the simplest ways to accomplish this is to provide the producer with two hoppers.

A number of devices for removing the ash and clinkers from the producer are in use. This has always proven a difficult problem. The aim has been to reduce the manual labor and decrease the loss of combustible through the ash. Grates for holding the fuel bed have been largely done away with in gas producers because their life is short, and the removal of clinkers from them is a very tedious and difficult operation. Another disadvantage is that during the period in which the clinkers are being removed the producer has to shut down. In modern continuous producers the ashes and clinkers are removed during the operation of the producer. This is affected either by a water seal or by mechanical draught processes.

The draft in nearly all cases is produced by means of a steam jet blower. Plate XXVIII, Figure 2, illustrates one type in use. Steam jet blowers when properly constructed have the advantage of being easy to regulate, and not get out of order readily. Also each producer is independent with respect to blast when equipped with this type of blower.

Plate XXVII shows a cross section of a Bradley Gas Producer,

manufactured by the Duff Patents Company, Inc., of Pittsburgh, Pa. Figure 1, Plate XXIX, shows this producer as it appears when set up over a water seal. The fuel bed is supported by its own ash, which rests on the bottom of the water seal, which completely seals the base and prevents the leakage of gas or air. The ash is shoveled out of the water sealed bottom from time to time, no skilled labor being necessary for this operation. No heat is lost in the ashes taken out, such heat being utilized in the formation of steam which rises up through the fuel, and, therefore, lessons the amount of steam required for blowing. There are two sets of grates running parallel with the steel water pan and from wall to wall. A dividing plate is provided in the center of each grate for the purpose of securing four separate and distinct blasts from four steam jet blowers. The grates are provided with numerous slots for the distribution of the air. This results in an uniform and even combustion of the coal and also gives a perfect control over the temperature in the different parts of the furnace.

Plate XXIX, Figure 2, illustrates the Duff Gas Producer as manufactured by the H. L. Dixon Company of Pittsburgh. This is very similar to the Bradley. These producers are made in two sizes. The standard has a shell ten feet in diameter and 11 feet in height; measures 7 feet by 7 feet inside of the lining and has a steel water pan 7 feet wide. It has a brick arched top, provided with one central bell hopper and six poke holes. The large size has a shell 12 feet 3 inches in diameter and 11 feet 6 inches in height, measures 7 by 9 feet inside the lining and has a steel water pan 9 feet wide. It has a brick arched top provided with two bell hoppers and nine poke holes. There are two blow pipes. The shells in both sizes are constructed of 3-16 inch gauge material.

Plate XXX shows the standard type of Hughes producer, manufactured by the Wellman-Seaver-Morgan Company of Cleveland, Ohio. This producer consists of a revolving brick lined shell with water seals at top and bottom, enclosing the coal to be gasified, an ash support attached to and revolving with the shell, carrying a blower supplying steam and air, and water-cooled top plate with a depending, vibrating, water-cooled poker. In operation the incandescent zone of fuel rests upon a bed of ashes extending from the ash pan to a point ranging from 6 to 10 inches above the blower hood. The incandescent zone is from 10 to 30 inches deep, according to the demand for gas, and the consequent condition of the fire. Over this, green coal is spread to a depth of 4 to 8 inches. The water-cooled poker, supported by the stationary top of the producer, and extending through the green coal zone and partly into the incandescent zone, moves in an arc between the center of the producer and a point within a few inches of the shell lining. As the poker swings backward and
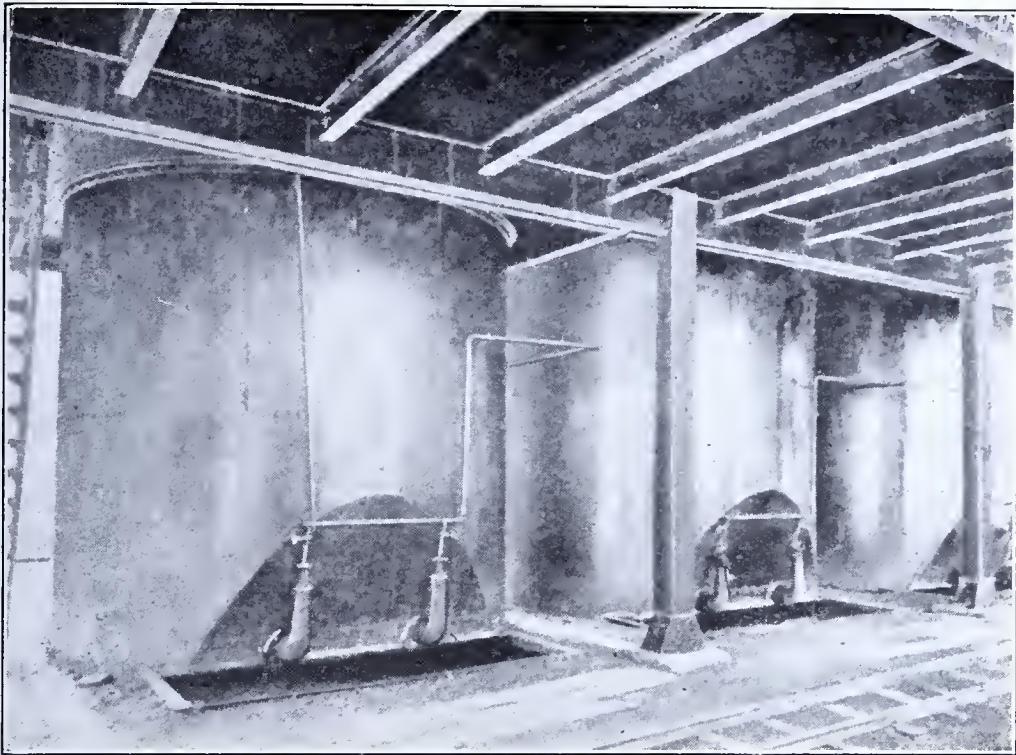
PLATE XXIX.

Fig. 1.   Bradley hand poked gas producer, installed.
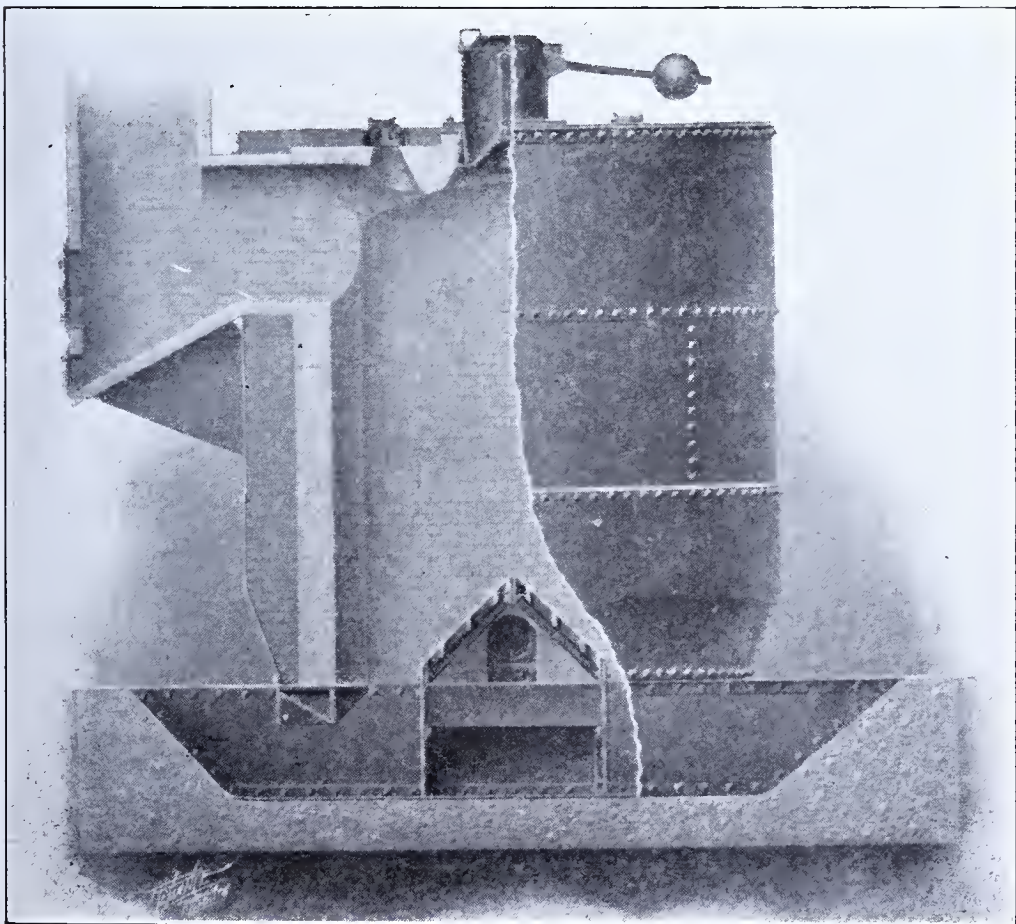
Fig. 2.   Duff gas producer (elevation and section through neck).
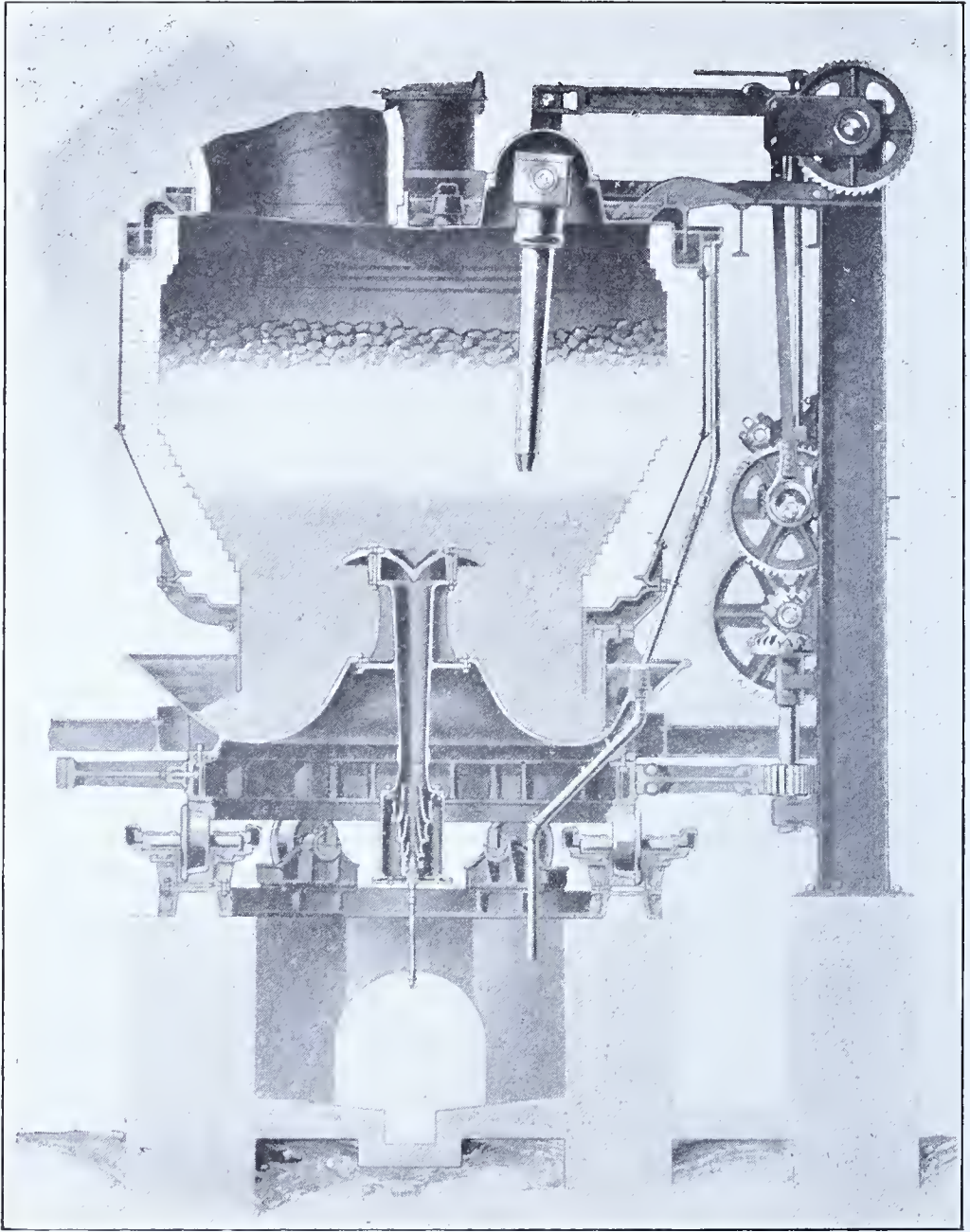
PLATE XXX.

Hughes producer (standard tpye).
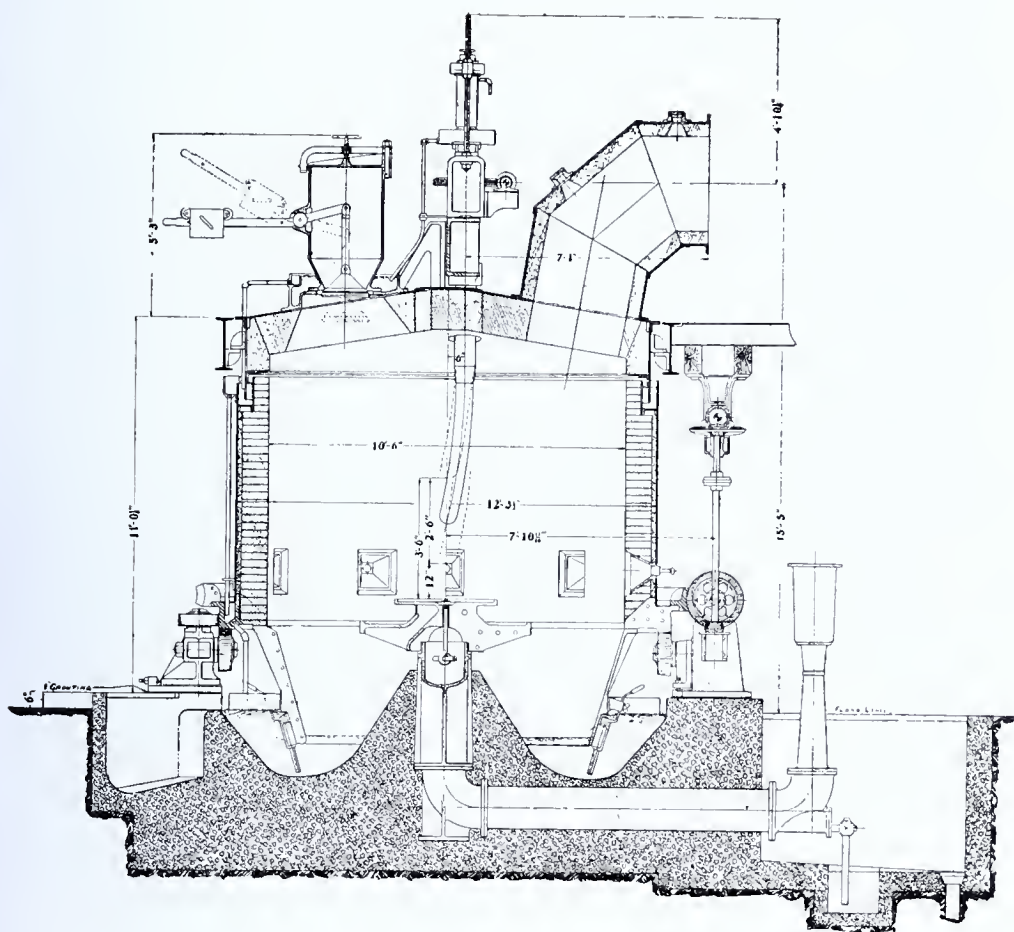
PLATE XXXI.

Mechanically stirred producer, as built by R. D. Wood and Co.

MAP OF PENNSYLVANIA, SHOWING DISTRIBUTION OF COALS BY FUEL RATIOS.
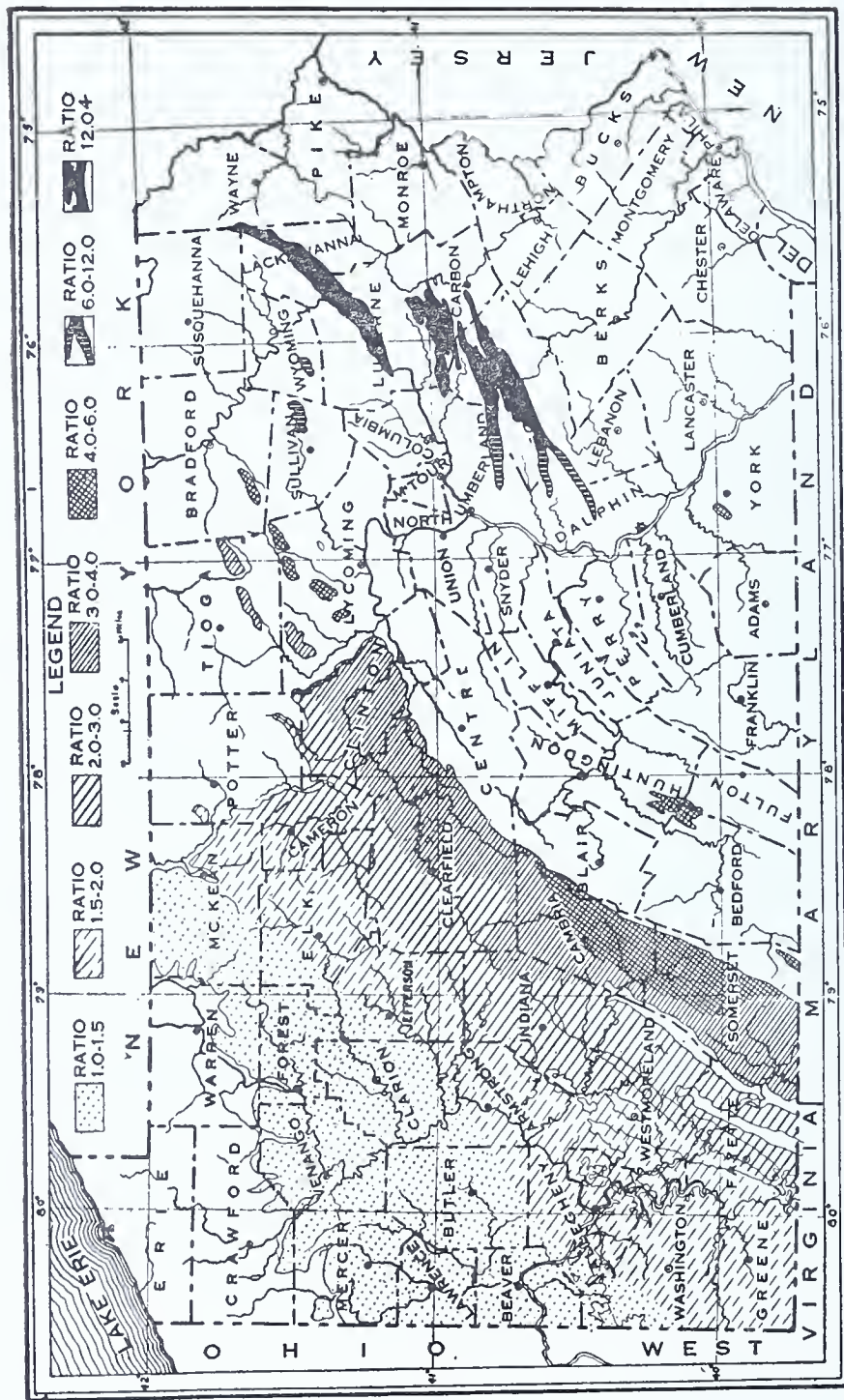
PLATE XXXII.

forward, the producer shell slowly revolves, so that the path in the fuel taken by the poker forms a series of ellipses. This prevents inequalities in the fuel bed due to unevenness of feed and blow holes which tend to develope in the incandescent zone. It is also designed to overcome the difficulty experienced with many bituminous coals which tend to coke. These coals tend to become semi-plastic during the coking process and form a more or less solid mass which interferes with the free discharge of the gas generated. The revolving fire bed and mechanical poker keep this mass disintegrated. There are two types of the Hughes Producer, a standard type in which the ashes are discharged through a water seal, and a self cleaning type.

Another type of gas producer with mechanical stirrer is shown in Plate XXXI. This is built by the R. D. Wood Company of Philadelphia. It also consists of a lower revolving shell with a water seal at the top and bottom, and an upper stationary one with an arched fire brick top. There are two water cooled stirrer bars, whose lower portions are curved to permit a thorough agitation of the fuel bed. These bars are given a rotary motion by means of worm gears while at the same time the whole fuel bed is revolving about a central axis with the rotation of the lower portion of the producer. This keeps the material thoroughly disintegrated and tends to prevent the formation of clinkers. A plough attached to the rotary shell removes the ash uniformly and discharges it at a fixed point.

All the producers described are designed for the use of bituminous coal, which is the principal fuel used for making producer gas in Pennsylvania. Plate XXXII shows the distribution of the coal fields of Pennsylvania by fuel ratios.

CHAPTER VIII.

POTS AND FURNACES FOR THE FUSION OF GLASS.

Two types of furnaces are used in the manufacture of glass, namely, pot furnaces and tank furnaces. In the former the glass is fused either in open or closed pots, while in the latter it is fused in large, usually rectangular shaped, open hearths.

Fire Clay.

Pots for pot furnaces and blocks for tank furnaces are made from special grades of refractory clay, which according to Ries should conform to the following requirements.[27]

1. Sufficient refractoriness to withstand the highest heat used, without changing form.

2. Great plasticity, such that the addition of 50% to 60% of grog will not affect it appreciably.

3. The clay must burn dense at as low a temperature as possible.

To these may be added that the clay should have little tendency towards the separation of substances from it which will contaminate or color the glass, and also that it must possess toughness and have low air and fire shrinkage.

A clay is generally considered sufficiently refractory for making glass pots if its fusion point is the same as that of cone 30, approximately 1,690°C, or 3,074°F. In judging the tensile strength, the size of the grog grains must be considered, and the relation in which the different sized grains are mixed. Glass pot clays should burn dense at a low temperature, so that when grog is added the temperature will not have to be raised too much to get the required density. The addition of grog raises this temperature, the extent depending upon the amount added.

Plasticity, shrinkage, temperature at which the clay burns dense, fusion point, and chemical composition are the properties of a clay, therefore, which must be investigated in order to determine its value for glass pots or tank blocks. Clays that fulfill all these conditions satisfactorily are comparatively rare in the United States. Thus far clays for this purpose have only been mined to any extent at St. Louis, Missouri, and Mineral City, Ohio. They are also known to occur in Pennsylvania and are undoubtedly present in other states, but up to the present time these have not been thoroughly tested. Before the present European war large quantities of glass pot clays were annually imported into this country from Germany and Belgium, but as this supply has now been temporarily cut off, and the stock of

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27. Bulletin New York State Museum, No. 35, 1900, pp. 786-787.

foreign clays on hand is becoming exhausted, American clays are being substituted with satisfactory results. So far as known no one American clay possesses all the required qualities, but it is a rather easy matter to so combine clays, each possessing some special quality or qualities, as to obtain a combination which is superior to any of the imported clays.

The fire clays of the St. Louis district, Missouri, are derived from an area which has its center in a section of the western portion of the city, known as Cheltenham, lying south of Forest Park, and extends southward into St. Louis County.[28] The geologic feature to which the presence of the fire clay within this area is mainly due is a faint geological basin. In this basin a little of the Pennsylvanian coal measures, usually less than one hundred feet in thickness, have been preserved from erosion. The coal measures here lie disconformably upon the St. Louis limestone of the Lower Carboniferous or Mississippian period. The coal measures consist mainly of shales and clays, with subordinate beds of limestone and a few thin beds of coal. At the base is a thin, but persistent, sandstone which forms the floor of the fire clay mines, all of which are in the very persistent overlying bed of fire clay, known as the "Cheltenham seam." The clay is secured much after the manner of coal mining, both shafts and slopes being operated. The depth below the surface is usually about seventy-five feet.

The thickness of the main, or "Cheltenham" bed varies greatly, ranging from one to twelve feet within a small fraction of a mile, but it rarely, if ever, pinches entirely out. Most of the mining is done where the thickness ranges from three to eight feet. Where it exceeds that thickness, as at the northeast corner of Cheltenham, the mining is generally limited to about eight feet from the best part of the bed. Near the center of the area, or within one mile to the south of it, the bed generally ranges about seven feet in thickness, all of this being good clay and taken out. At places the bed is mined where it has a thickness of only two and one-half feet.

The clay bed is rarely of uniform quality throughout its entire thickness. Its usual variations are due to changing proportions of silica and carbonaceous matter, and to the presence or absence of pyrite and other iron minerals. In the western part of the field pyrite, the chief impurity, is found mainly in the upper part of the bed. The best grade of pot clay occurs in the Oak Hill district about one mile south of Cheltenham.

Only the best of the clay is used for tank blocks and glass pots. The clay is carefully sorted in the mine and on the surface. Part of the clay is pure enough to be used in the crude condition, while another

28. U. S. Geological Survey, Bull. 315, 1907, pp. 315-321. Transactions American Ceramis Society, Vol. XVI, 1914, pp. 101-108.

grade is allowed to weather on the surface and is then washed and put on the market in raw and burnt blocks, or ground to various degrees of fineness. The clay remaining after the selecting and picking is used in the manufacture of other products, such as brick, where the highest grade of clay is not required. The following analysis is that of a plastic fire clay from St. Louis, Missouri.[29]

Analysis of Fire Clay from St. Louis, Mo.

SiO_2,	57.62
Al_2O_3,	24.00
Fe_2O_3,	1.90
FeO,	1.20
CaO,	.70
MgO,	.30
K_2O,	.50
Na_2O,	.20
H_2O,	10.50
Moisture,	2.70
SO_3,	.35
	99.97

The Mineral City, Ohio, flint clay, which has been used in the manufacture of glass pots and tank blocks occurs at the Lower Kittanning horizon of the Allegheny formation of the Pennsylvanian period.[30] It lies at varying distances below what is called Number 5 coal in Ohio and does not form a continuous bed, but occurs rather in lenticular shaped masses which range from four to five feet in thickness down to nothing, often pinching out suddenly and reappearing again unexpectedly.

In color this clay is a shade of gray, tending towards brown rather than blue. It is very hard and flinty, breaking like glass, and showing a conchoidal fracture with smooth surface.

The clay is won by mining and sent to the screening house where it is screened and hand picked. All doubtful lumps are broken into pieces with small hammers and any impure clay present is carefully removed. It is then ready for grinding. The clay is used in the manufacture of both glass pots and tank blocks. It is necessary to mix a plastic fire clay with it to serve as a bond.

Small quantities of clay from Pennsylvania have been used to mix with imported clays in the manufacture of glass pots and tank blocks, but up to the present time most of the clay used in this industry in the State has been imported from Missouri and Germany. Ries[31] gives the following analysis of a glass pot clay from Layton station, in northern Fayette County:

29. Economic Geology, 3rd. edition, by Heinrich Rier, p. 129.
30. Transactions American Ceramic Society, Vol. 8, 1906, pp. 353-363.
31. U. S. Geological Survey, Professional Paper 11, 1903, pp. 40-41.

Analysis of Glass Pot Clay from Fayette County.

SiO_2,	64.89
Al_2O_3,	24.08
Fe_2O_3,	.29
FeO,	.21
CaO,	.41
MgO,	.19
Alkalies,	1.03
H_2O,	9.29
	100.39

Much of the glass pot clay imported from Germany comes from Gross-Almarode. Here the refractory clay beds are from 32 to 42 feet in thickness.[32] The clays are of Tertiary age and according to Ries consist of the three following types:

1. Upper or pipe clay.
2. Crucible clay.
3. Glass pot clay.

Numbers 2 and 3 are less fat than 1, and form the main deposit. The former is the most important and the most refractory, its properties being such that it will stand great additions of grog and sand to diminish the shrinkage without too great loss of plasticity. It is used in the manufacture of crucibles. The upper or pipe clay is used in the manufacture of jugs, common cooking utensils, bricks and roofing tile. There are several grades present. The glass pot clay has the following composition:

Analysis of Glass Pot Clay from Gros-Almarode, Germany.

SiO_2 present as sand grains,	6.53
SiO_2, combined,	43.38
Al_2O_3,	34.52
Fe_2O_3,	1.66
CaO,	.76
MgO,	.37
K_2O,	1.51
SO_3,	.26
Loss on ignition,	11.04
	100.03

The best grade of glass pot clay mined is not purified before shipment. It is a clay of great density, plasticity and fair refractoriness. An important property is that it burns dense at a comparatively low temperature. Tests made on an air dried sample, when mixed with 25.80% of water gave an extremely tough paste. The bricklets made from it had an air shrinkage of 5.95%. At cone 09 (970°C or 1,778°F) the shrinkage was 11%. It is practically impossible to burn the clay without grog and prevent it from cracking. The clay is not a highly refractory one, for according to Professor C. Bishop its fusibility is very little above that of cone 27 (1,670°C or 3,038°F).

Silica Brick.

Silica brick is another refractory material used in the glass industry. They are employed in the construction of arches in fur-

32. U. S. Geological Survey, 19th. Annual Report, part 6, p. 418.

naces.   Silica brick are made from a nearly pure quartzite or "gan-
ister" as it is called by the brick maker.   The quartzite should con-
tain at least 97% silica and very little iron. The sand grains must
be thoroughly cemented by silica so that the rock will tend to break
across the grains rather than along the bond.   In central Pennsyl-
vania large quantities of this material are found in what is known
as the Tuscarora sandstone of the Silurian system, the so-called Me-
dina sandstone of the Second Geological Survey.

The formation is very resistant to erosion and, therefore, forms the
ridges or mountains of the central part of the State.   Much of it is
a quartzite of sufficient purity to be used for the manufacture of
silica brick.   At the surface it has been broken up into blocks of
varying size by the several agents of weathering, such as frost and
daily changes of temperature, so that the ridges underlain by the for-
mation are usually covered with a mantle of broken rock or talus
varying in thickness from a few feet up to twenty feet.   This talus
material where it is of sufficient purity and has not been too badly
disintegrated by the agents of weathering is used in the manufacture
of silica brick.   Sometimes quarries are also opened in the massive
rock itself underneath the talus material.   The rock is first crushed
in a jaw crusher and is then ground in a wet pan.   About two per
cent calcium oxide, in the form of milk of lime, is added and thor-
oughly mixed with the material in the pan.   The brick are then
moulded from this mixture by hand, in steel moulds.   They are dried
at about 150°C or 400°F and then burned at about 1595° or 2900°F
in down draft kilns.   This changes most of the quartz to cristobolite
and the lime between the quartz grains is converted into a lime silicate
which forms the bond.   The following is an analysis of burned silicia
bricks:[33]

Analysis of Silica Brick.

SiO_2,	96.10
Al_2O_3,	.90
Fe_2O_3,	.70
CaO,	1.80
MgO,	.14
Alkalies,	.39
	100.03

Manufacture of Glass Pots.

Melting pots used in pot furnaces are of two types, covered and
open; the former are used in the manufacture of lead flint glasses and
sometimes lime flint, although at present there is a tendency to grad-
ually replace pot furnaces by tank furnaces in the manufacture of
lime flint glass.   The use of open pots is now confined almost en-
tirely to the plate glass industry, although at one time they were
also used in the manufacture of window and other varieties of glass.

33. Mineral Industry, vol. 23, 1914, pp. 900-905.

PLATE XXXIII.
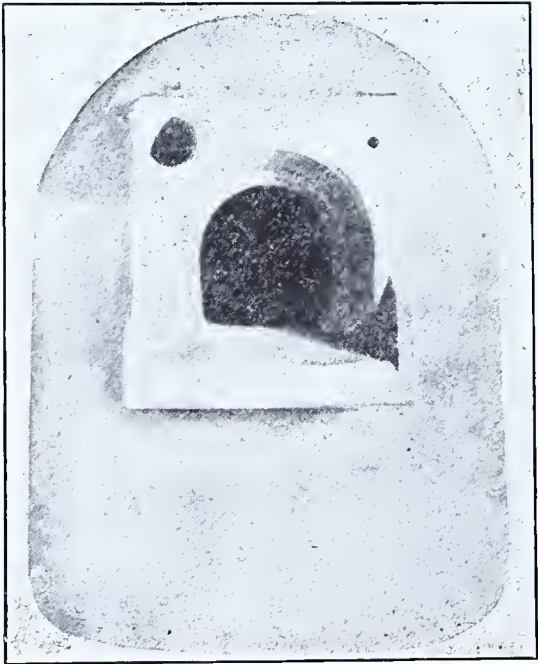
Different styles of glass pots.   (Ohio Valley Clay Co.)

PLATE XXXIII shows a number of different types of pots used in various branches of the glass industry.

On account of the severe service which is exacted from glass pots their manufacture requires the highest type of technical skill. The pots are of various styles and sizes, weighing anywhere from 1500 to 4000 pounds. These pots not only have to sustain their own weight under the high temperature of the glass furnace, but must retain a ton or more of molten glass whose ingredients comprise such powerful fluxes as the alkalies, lime and oxide of lead. In addition to this they are subjected to considerable strain due to unequal contraction when sudden chilling of the interior results from the addition of a new charge.

Three classes of materials enter into the composition of clay pots, namely, unburnt clay, burnt clay, and broken pot shells from old pots returned from service. The clays are selected with extreme care. Sometimes they are used in the raw state as they come from the mine, but frequently it is necessary to wash them to remove impurities, as has already been stated under the discussion of clays. The burnt clay and pot shells are called grog. Extreme care is exercised in chipping the old shells free from the adhering layer of glass on the inside, and the scorified and incrusted outside portion. These broken shells are taken from previously made and used pots whose record has been kept, so that their composition is known and no uncertainty of composition is encountered in their use. The object of adding burnt clay or grog is to facilitate the safe drying of the finished pots by diminishing the total amount of shrinkage which occurs when the plastic clay is allowed to dry, and afterwards when it is burnt, the burnt material having already undergone this shrinking process. The grog also acts as a skeleton which strengthens the whole mass and reduces the tendency to form cracks. The unburnt clay acts as the bond which renders the whole mass plastic, thus allowing it to be moulded into the desired shape and causing it afterward to burn to a dense product. Considerable quantities of German clay have been used for this purpose in the past.

The physical structure of the clay is a factor of prime importance. Two pot mixtures having approximately the same chemical composition, but containing different types of clays, will not give the same service unless their physical structures are also similar.

After the raw materials have been carefully selected the next step is to grind them to the proper fineness. This is an important operation. In grinding the shell care must be exercised that the small particals remain sharp, and of the proper size, although the fine powder which results from the operation is often used. Dr. Bischof is quoted by Dralle as recommending that the grog should be ground down to particles one to three millimeters in diameter. In American

practice the grog is usually crushed to a 4 to 8 mesh size, or to particles 2.4 to 4.7 millimeters in diameter, and the fine grog is removed by passing it through a 16x30 mesh screen. There are two factors which determine the size to which the material is ground. First, the smaller the grains the denser will be the resulting mass. It is important to have this as great as possible for so much more resistant will be the resulting pot against the fluxing action of the ingredients of the batch and the molten glass itself. On the other hand the denser the mass the more sensitive it becomes towards temperature changes. It is necessary, therefore, that the pot should have a distinctly granular structure to resist the strains set up by the temperature changes, thus allowing the pot to expand and contract without cracking. In practice a size must be adopted which strikes a mean between these two tendencies.

The mixture of raw and burnt clay, therefore, are so selected and ground to such fineness that they will burn to a density where very little granular structure is left, this being just sufficient to give the pot the necessary elasticity to withstand the temperature changes to which it will be subjected. The glass always tends to soak into the pore space between the grog particles, thereby loosening them, until finally they are surrounded by glass and float out, becoming stones in the glass. Dr. S. R. Scholes of the Mellon Institute of the University of Pittsburgh has, therefore, been experimenting with a vitrified surface coating for the inside of glass pots to cut down the surface of particles exposed and has met with encouraging results.

After the material has been crushed to the desired fineness the glass pot mixture is made up about as follows:

40% raw clay.

60% burnt material or grog, consisting of 30% pot shell and 30% burnt clay. Considerable variation exists in the practice of different manufacturers, however, some using as little as 30% raw clay, with 70% of grog, while others use as high as 50% of raw clay and only 50% of grog. The batch is thoroughly mixed and carried to the pug mill, where water is added and it is pugged several times. It is next piled up in large masses, compacted by hammering until solid, and covered with heavy canvass or sacks which are kept moist. The clay is then allowed to undergo a process of sweating or steeping which is called "ageing," and which extends over a period of from three to six months, or even longer. This long soaking induces a softening of its nature and develops toughness in the mixture.

When the clay has aged sufficiently to work it is again pugged and then sent to the clay trampers. These men tramp the clay with their bare feet until it gets the right consistency, sometimes tramping it over and over again from fifteen to seventeen times. All stiff lumps that would pass through the pugmill are thus detected and

PLATE XXXIV.

Fig 1.   Building glass pots.

Fig. 2.   Various sizes and shapes of Tank Blocks.

removed.   In some factories this tramping by foot has been replaced by careful pugging by machinery.

After the clay has gone through the tempering process it is transported to the pot rooms, where it is made into small rolls about three inches in diameter and six inches long, in which form it goes to the pot maker.   The first process in making the pot is the laying of the bottom.   This is sometimes tramped but more often it is laid on a large board.   The bottom of an average size pot is about four and one-half inches thick, laid in four or five layers of about one inch each, each layer crossing the preceding one at right angles.   It is made of sufficient size to permit the laying out and cutting down to the desired outside dimensions of the pot to be made.   An ordinary covered pot has a heart shaped base with a long diameter of about sixty inches and a short diameter of forty.   After it has been beaten down and cut to the shape desired the board, with the adhering slab of clay, is turned upside down on a special board, which has a lining of plaster of paris and a coating of sand which allows the pot to creep as it shrinks in drying.   This shrinkage amounts to one and one-half to two inches, according to the size of the pot.   The slab of clay is then cut from the original board with a wire strand and the mass of clay forming the bottom of the pot now rests on the special board.

The pot is then ready to be started from the bottom.   This is first scratched to make a rough surface that the clay will adhere to it. The clay of the sides is then put on in a series of hand and finger courses, each working being about three-eights to one-half inch in thickness.   These workings alternate, first one on the inside and then one on the outside, until the proper thickness is reached, which is about four and one-fourth inches at this point.   This is carried on until a height of from six to eight inches is reached.   The pot is then covered with a towel and allowed to remain a few days until it has stiffened up sufficient to hold the next working, which is called the "second working."   Plate XXXIV, Figure 1, shows several pots at this stage.   The operation is repeated, working about six to eight inches at a time until the pot reaches the point where the crown is to be turned.   The first spell of the crown is called "turning the shoulder."   After a few days wait, until the sides of the pot will hold up, the crown is worked on in two or three workings, and is beaten down into shape with a glass beater.

When the clay is closed in at the top of the pot it encloses a quantity of air inside the pot, which being somewhat compressed, tends to support the crown until it has had time to dry.   Care must be exercised to let the air out at the proper time or it will cause the pot to crack.   This is done by making a small hole at the point where the pot mouth is to be made.

8

The pot is now ready for the hood. The pad forming its lip is put on first, then the pot mouth is cut and the crown is smoothed on the inside, after which the hood is smoothed. The pot is now finished and the process of drying starts in. The pot is left on the board for several weeks and is then taken off and set in such a position that the bottom can dry. After the pot is sufficiently dry to move it is stored away in a warm room, where it stays from four to six months before being shipped. An even temperature of about 68°F is maintained throughout the year as the proper drying temperature, while hydrometers are used to register the amount of moisture that the air contains, so that this can also be maintained at the proper point. Excessive dryness or dampness is bad for drying pots, while draughts or air currents passing through the room are fatal. After the pots have passed through this drying process they are ready to ship to the glass house. They are not burned until they reach their final destination.

The process of making a glass pot is a very slow one taking anywhere from one month to six weeks. Each pot maker has from sixteen to twenty pots under his care at one time, working the clay on from five to six pots each day.

Open pots used in the plate glass industry are made in a very similar manner, except that they are open at the top and have a tapering circular shape. Usually a slightly different mix from that used for closed pots, especially those used in the manufacture of lead glasses, is used for open pots on account of the difference in fluxing action of the two types of ingredients going into these two varieties of glass.

Pot Furnaces.

The general arrangement of a pot furnace for closed pots is shown in Plate XXXV, while Plate XXXVI shows the exterior appearance of such a furnace on the working floor. This type of furnace is employed where a glass of good color is desired and where it is necessary to exclude furnace gases from the glass to avoid a reducing atmosphere, as is the case in the manufacture of lead glasses.

The regenerative type of furnace is now almost universally used in the manufacture of glass so as to utilize the waste heat of the gases escaping from the furnace in pre-heating the incoming air and gas. In this type of furnace the hot products of combustion, after leaving the furnace chamber proper, pass through chambers which are filled with loosely stacked fire brick, before reaching the chimney as shown in the illustration. The brick absorb the heat from the escaping gases and become heated to a temperature of about 1000°C. After an interval of about twenty to thirty minutes the path of the gas currents is altered. The incoming air and gas are now drawn through the heated brick checker work while the products of com-

Modified after Powell.

Gas

Reversing Valves ← To Chimney.

Air
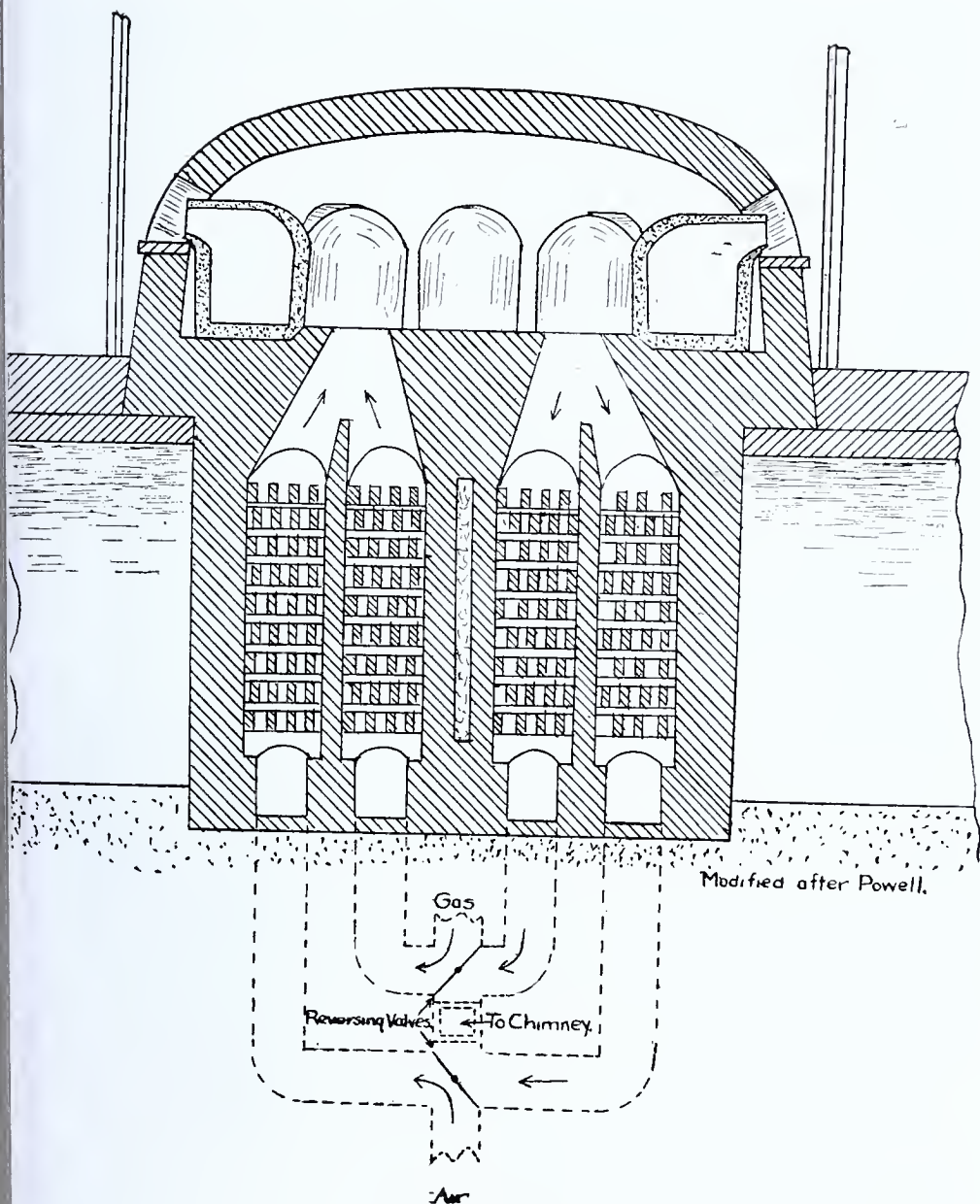
PLATE XXXV.

Section through a regenerative pot furnace.
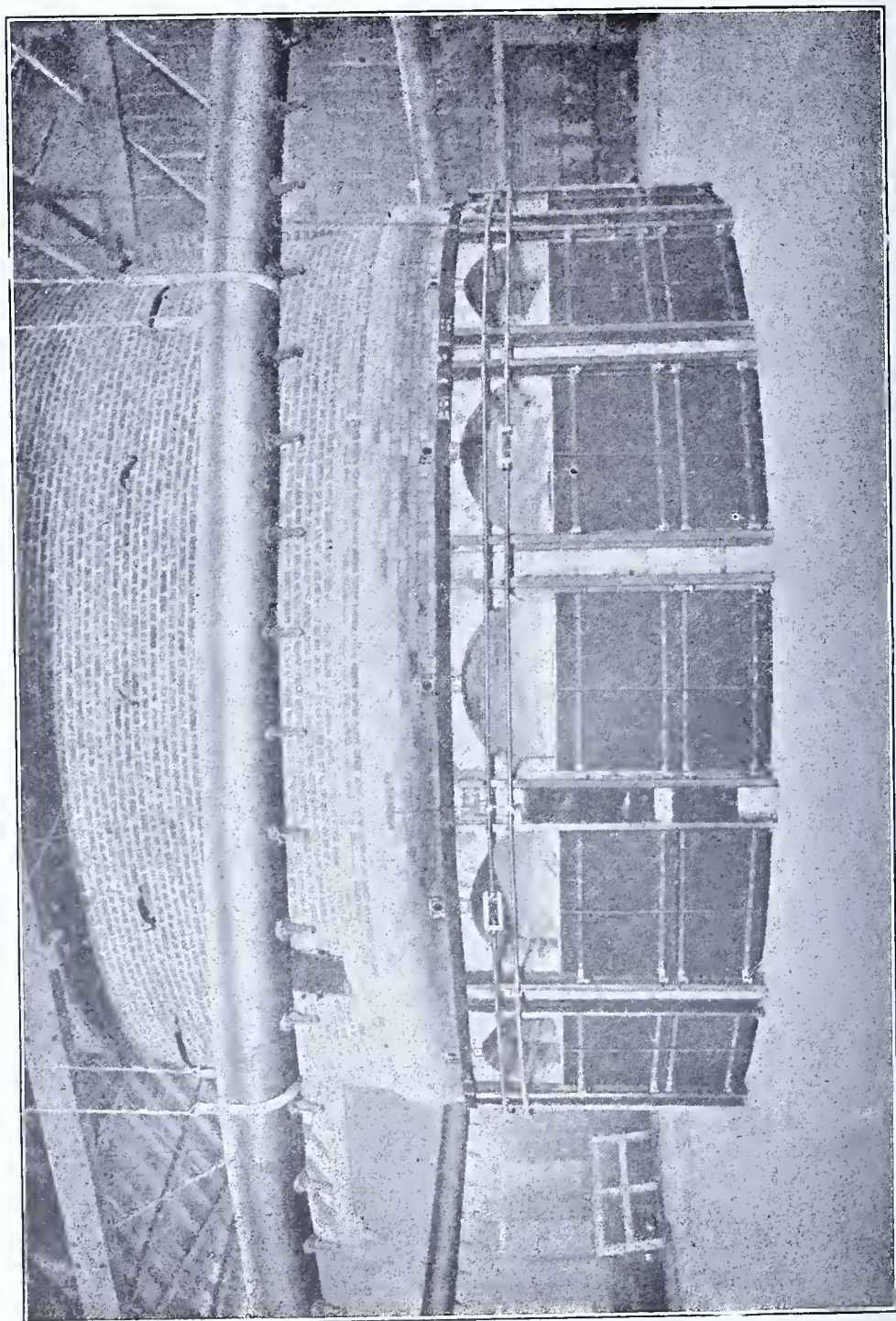
PLATE XXXVI.

Furnace. (H. L. Dixon Co.)

bustion are made to pass through a second set of regenerator chambers. The incoming air and gas are thus heated by absorbing the heat stored on the brick work of the regenerators. Two sets of regenerators are thus necessary for each furnace. While one set is being heated by the escaping gases from the furnace, the other set is giving up its heat to the incoming air and gas.

In a pot furnace the "ports" or apertures by which the air and gas enter the furnace chamber are placed in the floor of the chamber as shown in the illustration. There are two of these "ports." The gas and air enter at one, combustion occurs, the flame strikes the crown of the furnace, is deflected so that it plays about the pots, and then the gases of combustion leave by way of the second aperture. As has already been stated in the case of a regenerative furnace the direction in which the gases enter and leave the furnace is reversed every twenty to thirty minutes.

When a new pot is to be set in the furnace it is first heated slowly to the temperature of the working furnace in an annealing arch, or "pot arch" as it is called. It is then moved and set in the furnace proper as rapidly and with as little cooling as possible. After the pot has once been set in the furnace it is not allowed to cool again unless the furnace has to be shut down for repairs. A pot has an average life of about three months, although some pots may last as long as ten months. Pot furnaces are built to accommodate anywhere from ten, twelve, fourteen to twenty pots. These furnaces are usually run at temperatures of from 1400° to 1500°C, or 2552° to 2732°F.

The open pot furnace used in the manufacture of plate glass are rectangular in shape. They have a width of about three times that of a single pot and are usually made so as to hold twenty pots, ten on a side. Such a furnace is about forty-nine feet long, twelve feet wide, and five feet high on the inside. Opposite each pot is an opening large enough to allow the pot to be conveniently removed from the furnace for casting. This is kept closed by a fire clay door.

The air and gas flues come up at either end of the furnace and terminate vertically, or they come up vertically above the hearth level and turn so as to enter the furnace horizontally. The flame travels from one end of the furnace to the other, describing the arc of a circle. As regenerators are almost always installed the direction of the flame is reversed every twenty or thirty minutes. The regenerators are usually placed underneath the furnace, but they are so located that the occasional breaking of a pot will not allow the contents to pour into them. Pockets are placed underneath the furnace in which the glass resulting from such accidents may be caught and removed.

The life of an open pot is considerably shorter than that of a closed

pot, on account of the more severe useage to which it is put. The average life of an open pot is about six weeks. Open pot furnaces are heated to temperatures of from 1450° to 1540°C, or 2650° to 2800°F.

Manufacture of Tank Blocks.

Tank blocks are used in lining those portions of a tank furnace which come in contact with the molten glass. The requirements of a good block are that it must have high refractoriness, it must be able to resist the fluxing action of the ingredients used in making glass, such as lime, salt cake, etc., and the molten glass itself, it must be able to withstand the wearing action of the moving glass, and it should be a good non conductor of heat. The density of the block is also an important factor. It must be sufficiently dense to resist the fluxing and wearing action of the glass and yet not so dense as to allow cracking or checking on account of changes in temperature. The block must also be well burned before it is placed in the furnace, so as to reduce shrinkage.

Tank blocks are made in a large number of sizes, varying anywhere from 24x15x8 inches or smaller, up to 120x30x18 inches. They weigh anywhere from 50 to 3,000 pounds. As very few glass tanks are built exactly alike, each one necessitates a complete set of moulds for every block used in its construction.

The manufacture of tank blocks is a rather simple process when compared with the making of pots, but the same care must be employed to prepare a material which will withstand the wear to which these blocks are put in a tank furnace. The selection, grinding, preparing, and pugging of the clay is practically the same as that for pots, and very much similar mixtures are used.

After grinding, the clay mixture is tempered in wet pans to a certain consistency, learned by experience, for the particular clay used. After it has been tempered it is packed in bins and allowed to age. The longer this curing process lasts the better the clay will work. It is then run through a pug mill and comes out in the shape of cylinders about six inches long and three inches in diameter, ready to be taken to the moulding room.

The moulds simply form the four walls of the block. These are lined with water soaked clothes. The clay cylinders are thrown into the molds, one at a time, pounded firmly with the hand and carefully kneaded with the fingers to insure density, homogeniety and freedom from laminations and air holes or cracks. Sometimes the clay is tamped into the molds with pneumatic rammers, operating at an air pressure of 80 to 100 pounds.

As soon as the block is moulded the frame is removed and the block is covered with a cloth. It is allowed to stand until it has become leather dry. Then it is turned up on it side to allow the bottom to
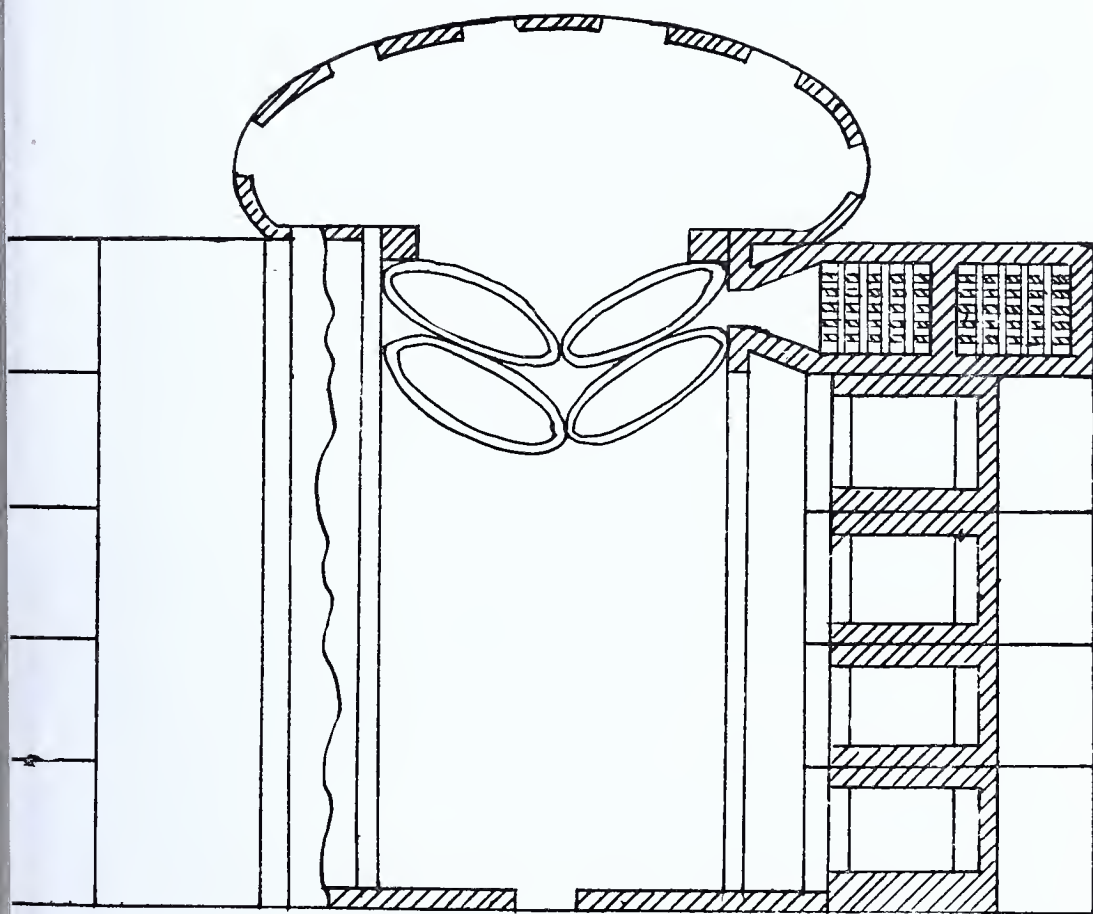
After Gillinder.

PLATE XXXVII.

Horizontal section of a continuous glass tank.

SILICA BRICK

REFRACTORY BLOCKS

FLUX LINE BLOCKS

BOTTOM BLOCKS

NOTE:-

FOR DETAIL INFORMATION NECESSARY
TO CONSULT ENGINEER.

GAS FLUE

AIR FLUE
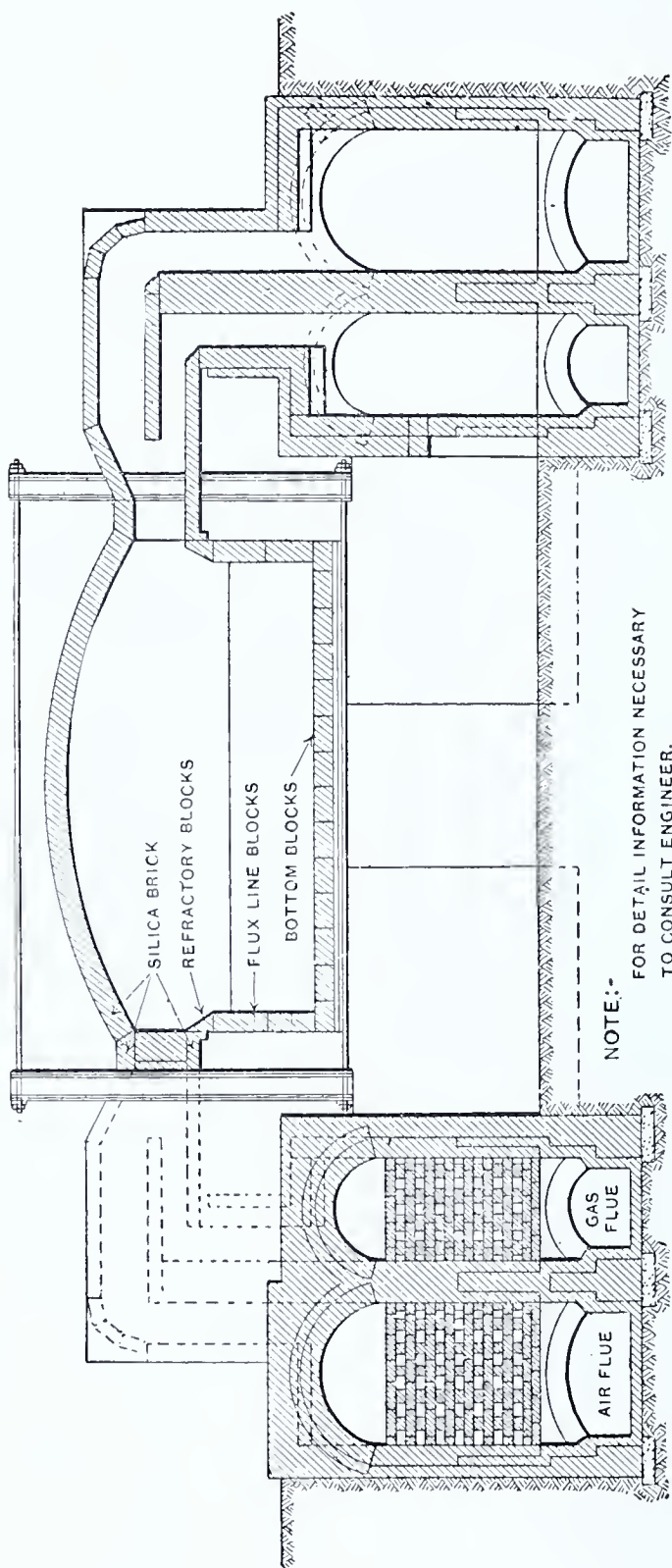
PLATE XXXVIII.

Cross section of typical producer gas glass tank. (Harbison-Walker Refractories Co.)

dry. The drying is done on floors which are heated from above, rather than from below, by steam pipes. This insures a more uniform temperature.

After drying the blocks are dressed to a given size, the angles being made true right angles and the faces being also trued up. Most of this work is done by hand with two edged axes and chisels. Finally the block is finished to the square and straight edge with a rubbing block

After dressing the blocks are ready to be burned. In the case of large blocks the drying is finished in the kilns. Round, down draft kilns are used. Great care must be exercised in this operation. The water smoking requires from one week to ten days or more, depending upon the dryness of the blocks. When the steam is all off the fire is raised rapidly and finished at a temperature of about 1370°C, or 2500°F in from two to three days.

Two grades of blocks are used in the tanks, one known as the common or furnace grade, and the other as the flux line grade. The furnace grade blocks are used in the bottom and part way up the sides where the glass is very viscous and in a chilled condition, so that the fluxing action is not very great, the blocks being thus protected from the intense heat of the upper part of the tank. The flux line blocks are used along the upper part of the sides of the tank where the glass is in the most fluid condition and hence most active as to its action on the blocks. Plate XXXIV, Figure 2, shows a number of different shapes of tank blocks.

<center>Tank Furnaces.</center>

Tank furnaces are glass furnaces in which the glass is brought to the molten state in large tanks, or basins, constructed of fire clay blocks, whose preparation has already been described. These furnaces may be divided into two types, namely:—continuous tanks and intermittent tanks. The former are worked continuously and are the type in most common use, while the latter are filled with batch one afternoon and worked the next day.

Plates XXXVII and XXXVIII show plan and cross section views of continuous tanks and illustrate their general arrangement. Great care must be taken that the blocks of the tank fit together perfectly, as the glass is sure to search out any cracks or fissures in the retaining walls. The depth of these tanks ranges from as little as twenty inches up to sixty inches in the larger ones. Their length and width also varies greatly. Continuous tanks for the manufacture of window glass are made over 110 feet long and 25 feet wide.

The ports for the entry of the gas and air and the exit of the products of combustion are usually placed in the side walls of the furnace, just above the level of the glass, but end port tanks are also

built.   Regenerators are provided as a rule, and air and gas come in first at one side of the furnace, and then at the other, the products of combustion always leaving at the opposite side.   This change is made every twenty or thirty minutes.   The tank itself is covered by an arch of silicia brick, as shown in the illustration.

These brick withstand high temperatures and have great mechanical strength.   On heating they expand instead of contracting, as do bricks made of fire clay, which makes them especially valuable in the construction of arches in furnaces.   Allowance must be made for this expansion in constructing the furnace.   This can be done by gradually slackening the tie bolts that hold the arch together, and correspondingly "taking up the slack" as the vault cools when the furnace is shut down.   Silica brick is rapidly attacked by molten glass and, therefore, can only be employed where it will not come in contact with the glass itself.

Continuous tanks, as a rule, are divided by means of fire clay obstructions, or floats as they are called, into several compartments, consisting of a melting or charging chamber, a refining chamber, and a working chamber.   See Plate XXXIX.   The batch is charged into the tank at one end, and after melting flows under the obstruction to the working end.   As fast as the glass is worked out new batch is introduced at the other end, so that the melting and working goes on continuously, thus maintaining a nearly constant level of glass in the tank.   Continuous tanks are operated at temperatures in the neighborhood of 1510°C or 2750°F.   The temperature is usually determined by means of pyrometers, chiefly of the thermo-electric type.

In the case of intermittent tanks the batch is shoveled into the tank and the work holes are closed.   Heat is supplied until the glass has reached the molten state and frees itself of gas bubbles.   Then the heat is reduced, the work holes are opened, and when the temperature has dropped sufficiently the glass is worked.   These tanks as a rule are filled in the afternoon and are ready to work the following morning.   For this reason they are often spoken of as "day tanks."   Such tanks are very wasteful of heat and hence are not used to any extent at the present time.

Relative Merits of Pot and Tank Furnaces.

Continuous tank furnaces have a considerable number of advantages over pot furnaces which have led to their adoption wherever they can be made to produce glass of adequate quality for the purpose desired. For this reason practically all bottle and window glass is now prepared in continuous tank furnaces.   On the other hand when special qualities of glass are required, in relatively small quantities, the pot furnace still remains indispensable.   Optical glasses and most colored glasses are examples of this kind.

PLATE XXXIX.
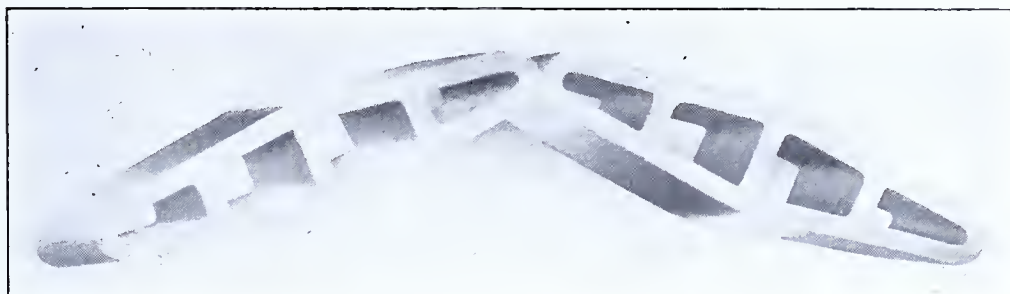
Floaters for Glass Melting Tanks.
Fig. 1.   Two-piece floater.
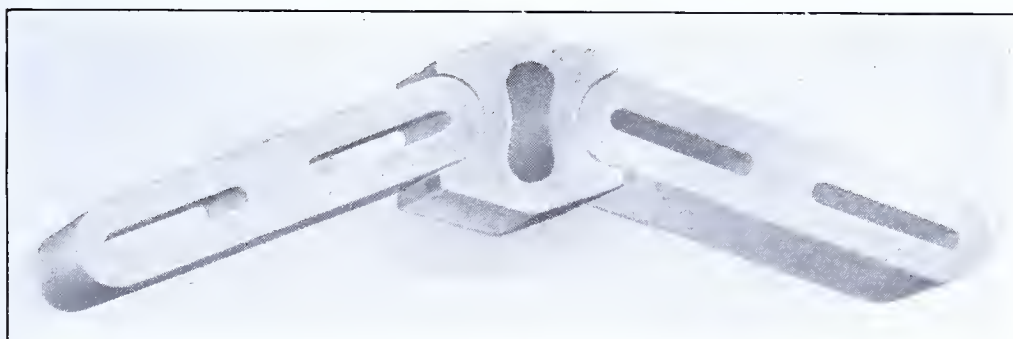
Fig. 2.   Three-piece floater.   (H. L. Dixon Co.)

Some of the more important advantages of continuous tank furnaces over pot furnaces are the more efficient utilization of the heat in the former, the greater output for a given size plant on account of the fact that the tank furnace is operated continuously, the economy in labor, the greater durability of the tank furnace owing to uniformity of temperature as compared with pot furnaces, and, finally, the saving in the costs of pots which are much more expensive to replace and have a shorter life than tank blocks.

Pot furnaces have the advantage over tank furnaces, on the other hand, in that the composition of the glass can be more accurately regulated and the molten glass itself can be more effectually protected from contamination from matter dropping into it, and from coming in contact with the furnace gases. In the manufacture of certain glasses, such as those containing lead, tank furnaces cannot be employed on account of the reducing action of the furnace gases and closed pot furnaces therefore must be used.

CHAPTER IX.

THE PROCESS OF FUSION.

The process of fusion is conducted in three stages. First, the raw materials are heated to a sufficiently high temperature so that the ingredients melt and react with one another to form glass. Then the temperature is raised somewhat to cause the glass to become more fluid, thus allowing the gases held by it to pass off more freely. This is called the "fining" process. Finally, the glass is allowed to cool down to working viscosity.

After the glass batch has been prepared as described in a previous chapter it is ready to be charged into the furnace. In the case of pot furnaces the material is charged into a pot which has been almost entirely emptied during the previous working out process. During this process the temperature has fallen considerably, so it is first necessary to raise this before a new charge is added, or the melting will not proceed satisfactorily. During the early stages of the melting large quantities of gas are given off which cause considerable foaming. The raw materials also occupy much more space than the finished glass. For this reason the charging cannot all be done at once, but fresh batches of raw material have to be added at proper intervals of time. Sometimes as high as four to eight "fillings" are necessary when closed pots are used. In the case of open pots one "topping," after the first charge has melted, is usually sufficient.

In the case of continuous tank furnaces the introduction of the batch into the furnace is a more simple matter, as the temperature is kept as near constant as possible. This allows the addition of new materials at almost any time. The amount added is so regulated that the level of the molten glass in the tank is kept as nearly constant as possible. The charge is introduced through a large opening or door at the "melting" end of the furnace, closed by means of a large fire brick block, suspended by a chain running over pulleys and counterbalanced by a weight. When charging is to begin this block is raised and the batch is introduced, either by hand with the aid of long handled shovels, or by means of a long scoop moved by mechanical means forward into the furnace, which is given a half turn to empty it, and is then rapidly withdrawn. See Plate XL.

The exact reaction which takes place in a glass mixture during the process of fusion are not definitely known, but the general lines along which these occur may be inferred from the end results and a few of the intermediate products that are known. The case of a lime soda glass, made from the proper mixture of sodium carbonate, limestone
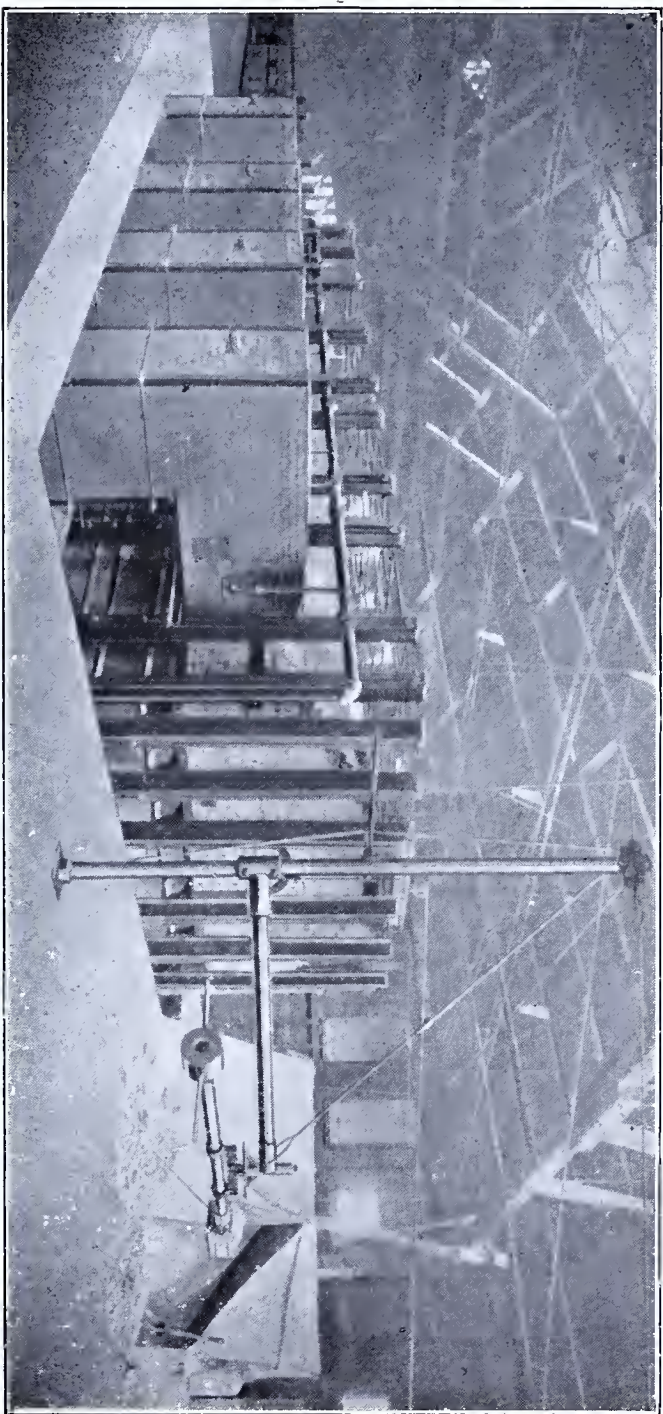
PLATE XL.

Side port tank furnace with crane. (H. L. Dixon Co.)

and sand, will be considered first. As the batch becomes heated the sodium carbonate is the first to melt. As the temperature rises it and the silica, the latter acting as a strong acid at the temperature of the furnace, react and sodium silicate forms and carbon dioxide is set free as a gas. In like manner the silica attacks the calcium carbonate of the limestone and a calcium silicate is formed, which is also accompanied by the liberation of carbon dioxide. Finally, all the carbonate present is decomposed with the complete liberation of the carbon dioxide. The molten glass now consists of a mixture of sodium and calcium silicates, probably partly present in a state of mutual combination and partly of mutual solution. These reactions may be expressed as follows:

$$Na_2CO_3 \pm nSiO_2 = Na_2OnSiO_2 + CO_2$$
$$CaCo_3 + 2SiO_2 = CaO \cdot 2SiO_2 + CO_2$$
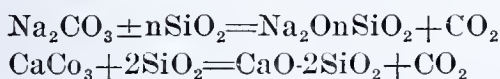
When the sodium is added in the form of a salt cake (Na_2SO_4) a more complicated set of reactions takes place. Silica alone, as has already been stated, is not able to decompose sodium sulphate sufficiently rapidly for successful glass manufacture at the working temperature of the furnace. For this reason a certain amount of carbon, in the form of coke, anthracite coal, or charcoal, has to be added to the batch. This aids in the reduction of the sulphate and its decomposition by the silica. The reaction may be expressed as follows:

$$2Na_2SO_4 + 4SiO_2 + C = 2(Na_2O \cdot 2SiO_2) + 2SO_2 + CO_2$$

In the case of a lead potash glass the silica attacks the potassium carbonate of the batch in the same manner that the sodium carbonate is decomposed in the lime soda glass batch. The silica also combines with the lead of the red lead (Pb_3O_4) employed with the formation of a lead silicate and the liberation of a portion of the oxygen of the lead oxide. The result in this case is a mixture of lead and potassium silicates.

If the batch has been satisfactorily selected and prepared and the process of fusion has been properly conducted, as soon as the last trace of the raw material has disappeared a transparent mass of molten glass results, which has numerous gas bubbles disseminated through it. It is now ready for the second stage in the melting process that is, freeing it from these bubbles. This is done by heating it further and to a higher temperature, thereby rendering it more fluid and thus allowing the gas bubbles to rise and pass off more readily. The larger these gas bubbles are the more readily they rise to the surface. In fact, in the case of very minute bubbles it is practically impossible to cause them to rise. An attempt is, therefore, made to compound such a mixture of raw materials as will yield large bubbles. If this is unsuccessful some substance may

be added to the molten mass that evolves a great many large bubbles, which on rising up through the molten glass sweep the small bubbles along with them. An inorganic volatile body, such as arsenic trioxide, is frequently used for this purpose, as are certain vegitable substances that contain a high percentage of moisture, such as potatoes. In this case the potato is usually placed in the crook of a forked iron rod and is dipped into the molten glass. The heat at once begins to drive off the moisture and decomposes the potato, thereby causing a violent ebullition of gas which carries the smaller bubbles present in the glass with it, and aids very materially in the "fining" process.

These latter methods can only be adopted in cases where the glass is melted in pots. They cannot be used in continuous tank furnaces. In the latter case only such mixtures can be employed as are capable of freeing themselves from their enclosed bubbles without assistance, and the furnace must be constructed in such a manner that the melting batch and glass as it flows from one end of the tank to the other meets at each point that degree and kind of heat which is required for that particular stage of the melt.

After the glass has become free from its enclosed bubbles of gas the temperature is allowed to drop until the glass assumes the proper working viscosity. This stage of the melt is called the "standing off" process. In the case of pot furnaces this is done by lowering the temperature of the entire furnace, while in the case of a continuous tank furnace the glass is allowed to flow to the working chamber of the furnace, which is always kept at the working temperature. After the dust and impurities have been removed from the surface of the glass, or "metal," as it is termed, it is ready to work. The scum which rests on the surface of the glass is called "gall."

Closed pot furnaces are heated up to temperatures of 1400° to 1500°C, or 2500° to 2730°F., while open pot furnaces are heated to temperatures of about 1400° to 1540°C., or 2550° to 2800°F. Continuous tanks are worked at temperatures somewhat higher than those of pot furnaces as a rule, that is from 1400° to 1510°., or 2550° to 2750°F., the higher temperatures being the more common ones used. Temperatures in glass furnaces are usually measured by means of pyrometers, chiefly of the thermo-electric type. Such a thermo-electric pyrometer, with platinum-rhodium couples, is capable of measuring temperature up to 1650°C., or 3000°F., within one per cent of accuracy. This instrument consists of a sensitive galvanometer, which indicates by the movements of a pointer over a carefully calibrated scale the current of electricity produced by heating the junction of a fine platinum and plantinum-rhodium or platinum-iridium wire, commonly termed the element. Each instrument has to be standardized and the scale graduated accordingly.

In the case of covered pots the ordinary practice is to work a pot every other day. No definite time, however, can be given for the length of melting, as this varies with the size and thickness of the pot, the kind of glass being melted, and the temperature of the furnace. Open pots in the plate glass industry are usually cast once each day. In the case of continuous tanks the operations of charging and working go on simultaneously at the two ends of the furnace.

In addition to the chemical reactions which take place in the batch materials, the chemical influence of the furnace gases on the glass is a factor of vital importance. The flame of a glass furnace is invariably reducing, yet the reducing effect varies in degree, depending upon the condition of firing. On account of this reducing action certain glasses, such as lead glasses (which must be melted under oxidizing conditions to prevent the reduction of any metallic lead in the glass, which would blacken it), have to be prepared in closed pots where the furnace gases cannot come into contact with the molten glass. Even in the case of lime flint glasses, when as nearly colorless product as possible is desired, the closed pot must be employed to obtain the best results.

Defects in the glass may usually be traced to impure materials, improper composition of the batch, improper mixing of the raw materials, or improper firing. Difficulty is also encountered at times if the clay pots or tank blocks employed in the furnaces are of poor grade. Some of the most common and troublesome faults encountered are excessive amounts of glass "gall," or scum, on the surface of the glass, excessive foaming during the melting operation, the presence of bubbles, stones, cords, or striae in the finished glass, devitrification, and high color or low color of the glass.

Glass gall is removed from the surface of the glass by skimming. Excessive gall is generally due to the undecomposed sodium sulphate in the glass which has either been added in the form of salt cake or was present in the soda ash used, or to sulphates present in some of the other raw materials employed. Glass gall usually rises to the surface, where it can be removed if the fining process is properly conducted. Otherwise it may remain suspended in lumps in the molten glass and finally separates as white blotches in the finished glass. One of the remedies is to use materials containing less sulphate. When sodium sulphate is used as a source of sodium it may be necessary to add more carbon, that the decomposition of the salt cake may go on more readily. Care must be taken, however, not to add any excess of carbon, as this is apt to produce a smoky or yellow color. Greater care in the "fining" operation and more thorough mixing of the batch may also prevent this difficulty.

Excessive foaming is usually due to the slow heating of the batch in the early stages of melting. This tends to cause a separation of

the heavier unfused material and the lighter fused material. The liquified salts enclose the slowly escaping bubbles of gas and the batch froths or foams. This can be prevented by heating the pot to a higher temperature before introducing the batch. so that melting will proceed more quickly and the rapid evolution of gases will prevent the separation of the fused and unfused portions of the batch.

The presence of bubbles in the glass produces what is known as "seedy" glass. This is usually due to too low a temperature or not allowing sufficient time during the "fining" process. It is very difficult to free a glass entirely from bubbles and in the case of some glasses this is impossible.

Stones in the glass consist of undissolved portions of the batch, or small particles of clay from the walls of the pot or tank. Cords are knotty or wavy veins having a greater viscosity than the surrounding mass, while striae are streaks or layers of different density running through the glass. By avoiding impure materials, improper mixing and proportioning of the batch, and too slow fusion, these difficulties may usually be overcome. Striae may also be due to large lumps of cullet. The addition of too much cullet may also produce these difficulties. Very often stones and cords are produced by charging the batch into too cold a pot or furnace. Striae are especially apt to be developed in lead glasses on account of the tendency of the lead silicate to settle out, due to its greater specific gravity. Such glasses, therefore, should not be allowed to stand any length of time in the pot before working.

Devitrification in glass is due to the tendency of the silicates which compose the glass to crystallize out on cooling. Certain silicates have a much greater tendency to crystallize than others, and therefore glasses containing them will tend to devitrify more readily. Devitrification rarely occurs in the pot or tank, but sometimes occurs during the working of the glass or the annealing operation. It may be due to too slow chilling of the molten glass during the working, or keeping it at the maximum temperature of the annealing oven too long, and cooling it too slowly. Often it is due to an improper composition of the glass batch.

A pink tinge in the glass is known as high color and is due to an excess of manganese. A green color on the other hand is known as low color, and is produced by an excess of iron.

CHAPTER X.

ANNEALING.

In working glass if it is allowed to cool at ordinary temperatures hardening takes place so rapidly that a tension develops between the molecules of the outer and inner layers of the glass. The outside layer naturally cools and hardens first, while the inside layers are still soft. Then as the inside layers cool and solidify they tend to contract and draw away from the outside layers, but, as the latter are already hard and rigid, instead of the whole mass contracting as a unit a tension is developed between the outer and inner layers, the amount of which depends upon the rapidity of the cooling. This tension makes the glass very tough and strong and gives it the quality of resisting sudden changes of temperature as long as the surface remains unbroken. If this is scratched or cracked, however, the tension is relieved and the glass flies to pieces. For this reason all glass intended for ordinary uses has to be cooled slowly, so that the outside and inside layers will cool as nearly simultaneously as possible and all tension thereby avoided. This operation is called annealing the glass.

Some interesting investigations have been conducted by Mon. L. Grenet, a French engineer, to determine the limits within which annealing takes place.[34] His results lead him to the conclusion that those limits are quite small and that there is only a comparatively short range of temperature where tension develops. For St. Gobain plate glass he found that these limits were between 943° and 1087°F., for a glass of composition 55% SiO_2, 15.50%CaO, and 13% Na_2O, between 941° and 1154°F., and for an extremely basic silicate compound of composition 55% SiO_2, 18% CaO, 21% Na_2O, and 6% BaO, between 788° and 932°F. The temperatures at which these glasses first began to soften and lose form were ascertained to be 1440°, 1521°, and 1350°F., respectively. If these observations prove to be correct, the range of temperatures through which great care must be taken in annealing is approximately but 200°F. Above this maximum, and below this minimum, temperature the glass may be cooled quite rapidly without developing tension. Grenet also observed that devitrification may take place below the temperature at which glass softens, but that in as much as the softening point was so much above the maximum temperature at which tension may develop, this should never be a source of trouble in annealing.

There are two types of annealing kilns or ovens in use at the present time; namely the intermittent kiln and the continuous kiln or

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34. Linton. The Mineral Industry for 1899. Vol. 8, p. 237.

lehr. The intermittent kiln consists of an arch and hearth on which the ware is laid. It is usually heated with gas, but coal or wood may also be used. In the case of hollow ware and flint glass kilns of this type of firing are so arranged that the heat is evenly distributed over the interior while the glass is laid in. The draught is kept at a minimum at this stage, so that the kilns becomes filled with the products of combustion. When the kiln is filled, it is sealed and the proper rate of cooling is accurately regulated by adjusting the draught with the stack damper.

This type of kiln is still in use in many plants for annealing plate glass, although there is a tendency at the present time to introduce continuous kilns or lehrs in this branch of the glass industry. Usually a separate chamber is provided for each plate of glass to be annealed. The slabs are laid flat on the stone bed of the kiln. This bed is built up of carefully dressed stone, or blocks of fire brick imbedded in sand, in such a way they can expand freely laterally, without causing any tendency for the floor to buckle upwards during the heating. The whole chamber is heated to a temperature at which the glass still shows slight plasticity. The hot glass slabs from the rolling table are slid upon this bed and in the course of a few hours gradually settle down to the contour of the bed, from which they are not removed until quite cold. This takes anywhere from three to five days. Care must be taken in arranging the air passages in the walls and floor of the kiln in such manner that the whole kiln will cool at an uniform rate.

Optical glass has to be put through a very careful final annealing process in cooling it, from the red heat at which it has been moulded, down to ordinary temperatures. The length of time occupied by such cooling depends very much upon the size of the object and the degree of refinement to which it is necessary to carry the removal of small internal strains in the glass. For many purposes this can be accomplished in from six to eight days in large kilns. In other cases where perfect freedom from internal strain is required much greater refinements are necessay and special annealing kilns whose tempeature can be more accurately regulated and maintained are employed. In these furnaces the cooling can be carried on so gradually that a rate in which a fall of one degree C, occupies several hours can be maintained.

Continuous kilns, or "lehrs" have replaced intermittent kilns to a large extent. They are now employed for annealing much of the hollow ware and flint glass produced, all of the window glass and a considerable amount of the plate glass manufactured. This is due to the fact the lehr can be operated much more cheaply than the intermittent kiln. The capacity of the factory is considerably in-

PLATE XLI.

Fig. 1.　Lehr fronts.
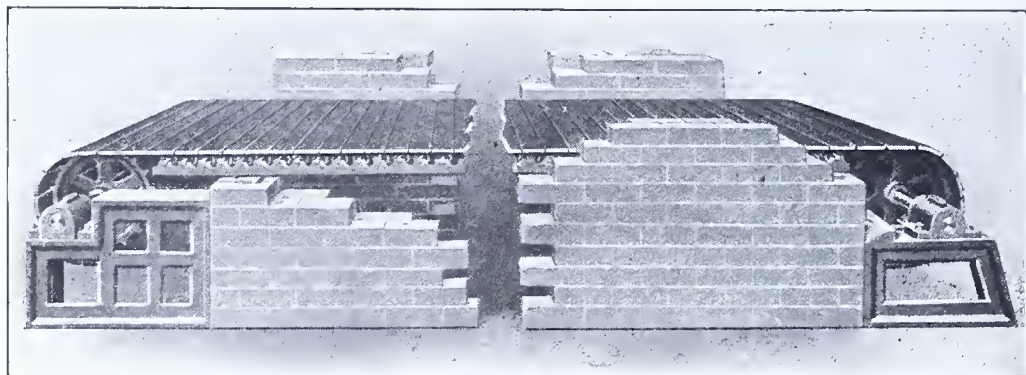
Fig. 2.　Endless carrier for lehrs.　(H. L. Dixon Co.)

creased for the same space occupied, and the same outlay for construction and fuel.

.A lehr consists of a long tunnel heated at the entrance to a temperature just below the softening point of the glass. The temperature falls gradually from this point until at the other end the glass emerges at ordinary atmospheric temperature. In the case of lehrs for hollow ware the articles are stacked on trays, linked together by an endless band, and as each tray is filled it is pushed forward into the lehr, the trays thus following one another down the tunnel at a speed depending on the rapidity with which each trays is filled. When a tray has been emptied at the cool end it is returned to the charging end. Figure 1, Plate XLI shows a front view of three such lehrs, while figure 2 shows a slightly different type of carrier than the trays described above. This is an endless carrier which can be moved continuously or intermittently at any desired speed. This does away with the carrying of the trays from the back to the front of the lehr. When bottles are being annealed the first twenty feet of such lehrs are usually heated to a temperature of about 540°C., or 1,000°F. They are made about seventy feet long and it takes the bottles about three hours to pass through the lehr.

Window glass is annealed continuously in connection with the flattening process. After the sheet of glass has been flattened it is laid in at one end of the lehr, which opens into the flattening oven and is drawn slowly to the other end. The Tondeur rod lehr is the type which is commonly used today. This consists of two sets of horizontal rods or bars, so attached to a series of shafts that one set may be raised or lowered below the other set, and slides free in a series of sheaves. The glass is laid upon this movable set of rods and is drawn forward the width of one sheet. The shafts are then revolved sufficiently to drop this set below the other set, which receives the glass, while the movable rods are allowed to slide back to their original position and raised to receive another sheet. These lehrs are made in sizes varying from $6\frac{1}{2}$ feet wide and 44 feet long, to $8\frac{1}{3}$ feet wide and 52 feet long.

The Tondeur rod lehr system has also been adopted for annealing plate glass in the case of sheets under 200 square feet in size. Lehrs in use for plate glass are made as long as 600 feet. The temperature at the heated end is usually raised to 650°C., or 1,200°F.

CHAPTER XI.

PROCESSES USED IN WORKING GLASS.

Glass owes its value to the fact that it is a hard, transparent, rigid body at ordinary temperatures, offering great resistance to chemical change, which becomes plastic at high temperatures, thereby allowing itself to be moulded into any desired shape. As has already been stated under the fusion of glass, the last stage in the melting operation is the cooling of the glass to the viscosity necessary for working it into the shape of the various articles that are made from it. The procedure followed after that in manufacturing the different kinds of glass goods varies somewhat for each type. Therefore, a brief outline of the processes employed in the manufacture of bottle glass, blown and pressed glass, rolled or plate glass, window or sheet glass, and optical glass is taken up here.

BOTTLE GLASS.

Ordinary bottle glass is one of the cheapest grades of glass manufactured, therefore, great economy must be exercised both in the selection of raw materials and in the methods employed in its manufacture. Bottle glasses as a rule are of the lime soda type, but other constituents, such as iron oxide, alumina, are also invariably present. Fortunately color is not an item of great importance and a considerable range in composition is permissable, so that the purity of the raw materials entering into the batch does not have to come up to the high standards set for the better grades of glass.

A good bottle glass must, however, come up to certain requirements. It must be sufficiently strong to resist the internal pressure to which it will be subjected when used for the storage of fermented or effervescent liquors, as well as the shock of ordinary use. It must remain practically unattacked when called upon to contain more or less corrosive liquids. There are also certain requirements essential from the manufacturer's standpoint. These are that it shall be comparatively fusible, easily worked, and readily annealed.

Since color is not such an important item in ordinary bottles, sand used in their manufacture may contain a higher percentage of iron than those used for other types of glass, and therefore a cheaper grade of sand may be employed. For white bottles the iron content should not exceed 0.5% Fe_2O_3, but in the case of other bottles sands containing anywhere from 0.5 to 7.0% Fe_2O_3 are used. Iron as has already been stated, gives the glass a green or greenish yellow color, deepening to a black opacity if the quantity of iron is high. The lighter shades of green may be practically neutralized by adding small
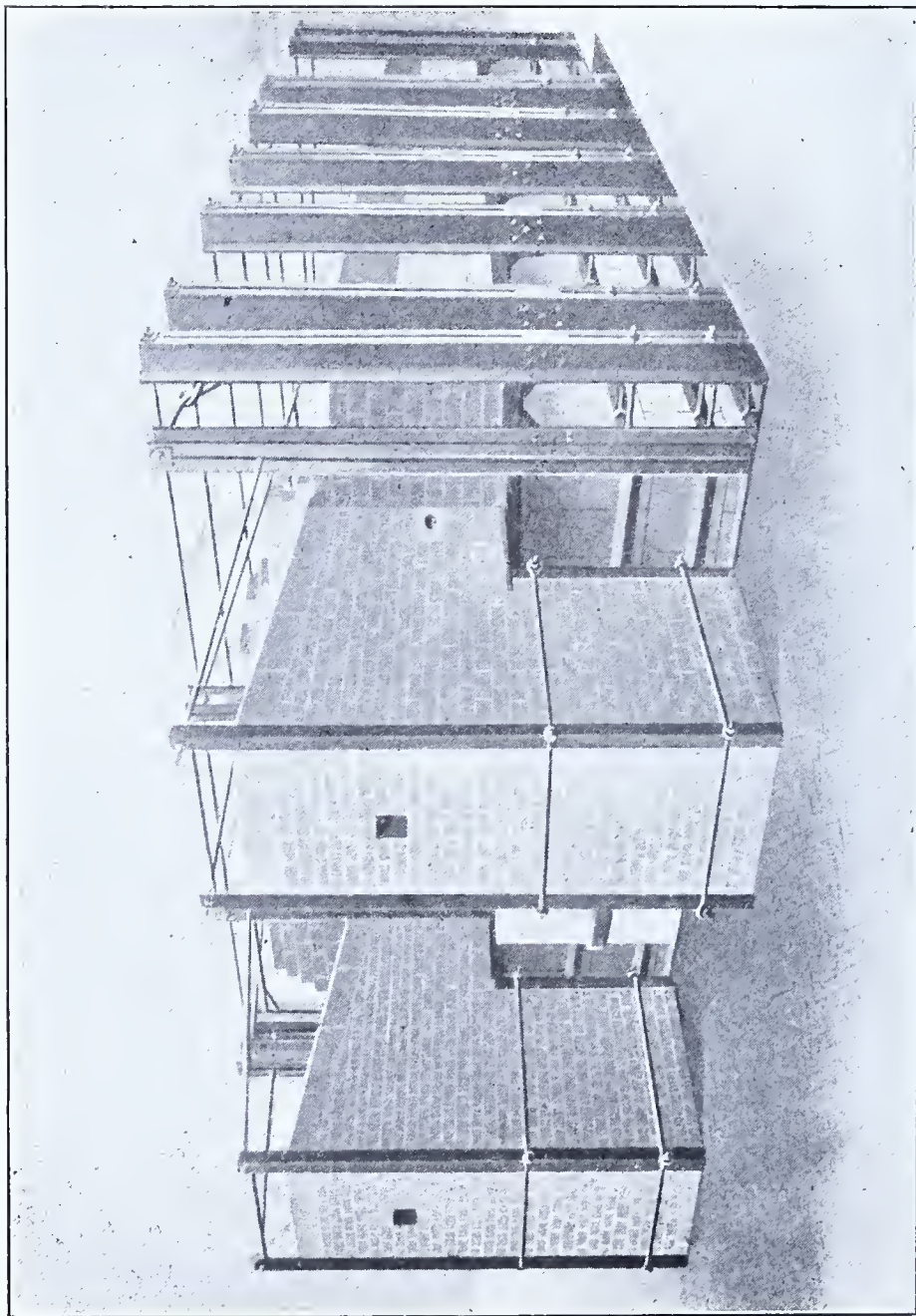
PLATE XLII.
End port tank furnace. (H. L. Dixon Co.)

quantities of manganese oxide to the glass. If the percentage of iron is higher, however, colors ranging from light amber to purple are produced by the addition of manganese. This is sometimes done, as in the case of brown beer bottles.

The raw materials commonly employed in the manufacture of bottle glass are sand, salt cake, soda ash, and limestone. A certain amount of manganese oxide is also usually added, and where salt cake is used some carbon in the form of charcoal, coke, or anthracite coal must be employed. Some typical bottle glass batches have already been given in a previous chapter. As has been stated the absolute chemical purity of these materials is not an item of such importance as in the case of other kinds of glass and, therefore, cheaper grades of material can be used.

Practically all bottle glass is now produced in continuous tanks, as these are much more economical to operate than pot furnaces and give very successful results in the manufacture of this type of glass. Both the end port and the side port tanks are used. In the end port tank the gasses both enter and leave at the charging end, the flame being of the horse shoe type. Plate XLII illustrates such a furnace. The side port furnace has already been described. The working end is usually made semi-circular in shape. The raw materials are thrown in at the charging end and the molten glass flows uninterruptedly down the length of the tank to the colder, semi-circular end, where the working holes are situated. Fire clay rings are sometimes kept floating in the glass at this end to retain on their outside the scum or "gall" carried down by the glass. The gatherer takes his glass from within these rings.

Great improvements have been made in recent years in the methods used in manufacturing bottles. The tendency at present is to do a large part of the work formerly done by men by machinery, and some marvelous mechanical devices have been developed to accomplish this.

Where bottles are still made by hand the first step is to gather the requisite amount of glass from the furnace. This is done by means of the bottle blowers pipe, which is an hollow iron rod, five to six feet long provided with a slightly enlarged end or "nose" upon which the glass is gathered. Several gatherings are usually necessary, some skill and practice being required on the blower's part to judge when the right weight of glass has been gathered to produce the bottle desired. This mass of glass is next distended slightly by the blower, and is then placed in a cast iron mould whose interior has the external shape of the bottle. This mould is made of several parts, usually two working on a hinge. The mould is opened by means of a pedal or lever to receive the glass and is then closed. By blowing into the pipe the glass is made to assume the shape of the

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mould.   After this is accomplished the mould is opened and the neck of the bottle is broken from the rod to which it is attached.   The shaping of the neck is done by hand by another workman.   It is first heated up to the desired viscosity in a small furnace, or "glory hole," and is then moulded into the desired shape by the aid of specially shaped tongs.   After this has been done the bottles are ready to be annealed.

Very few bottles are any longer made by the above process.   At present machines are used in which not only the neck of the bottle is pressed to the desired shape, but the bottle itself is blown in a mould by means of compressed air.   In the simplest type of these machines the glass is still gathered from the furnace by hand.   Instead of using a blow pipe for this purpose, however, a light iron rod is used. The necessary amount of glass is gathered from the furnace by the gatherer and placed in a mould, which has the form of the neck with a space underneath, usually in the shape of a tapering cylinder, to hold the requisite amount of glass to finish the bottle.   As soon as the viscous glass has been placed in the mould a plunger is brought down which presses the upper portion of the glass into the shape of the neck, while the glass underneath takes the shape of the tapering cylinder.   This mass of glass is now called a blank.   It is removed from the first mould by means of a ring, either by hand or mechanic- ally, and is placed in another mould which has the form of the fin- ished bottle.   It is then blown to the shape of the mould by com- pressed air.   When the bottle comes from this mould it is ready to be annealed.   Two men are required to operate such a machine, a gatherer and a presser.   A further improvement consists in hav- ing the glass flow in a thin stream from the furnace into the first mould, the stream being cut off automatically by a knife each time sufficient glass has flowed into the mould.   The rate at which the glass flows out can be regulated by enlarging or decreasing the size of the opening through which it flows.   This done away with the hand gathering.   In order to have this process go on continuously duplicate mould have to be provided with each machine, so that as one is withdrawn another takes its place.   These machines are of the semi-automatic type and require only one man to operate them. In addition one boy is usually employed to each machine to take away the finished bottles.   Plate XLIII illustrates machines of the type above described, in which both the pressing of the neck and the blowing of the bottle itself are done mechanically.

The greatest invention in the bottle industry in recent years has been a still better type of machine than the ones thus far described, one which operates entirely automatically.   This is known as the Owens automatic gathering and blowing machine, from the name of its inventor.   It is shown in Plate XLIV.   This machine takes the
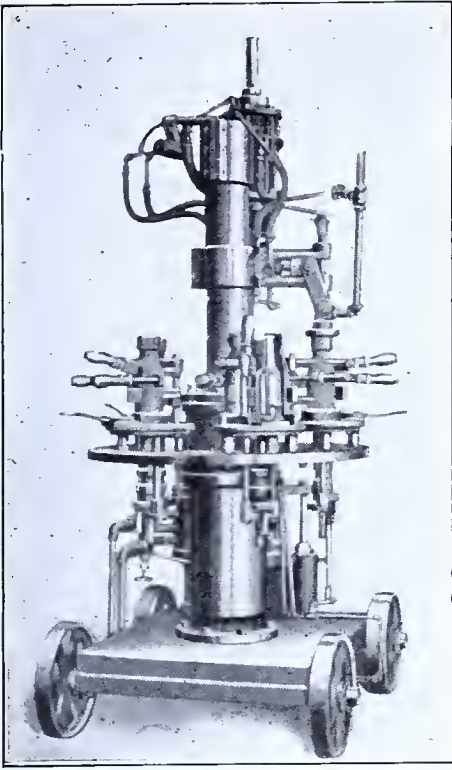
PLATE XLIII.

Fig. 1. Semi-automatic pressing
and blowing machine for
narrow neck bottles.
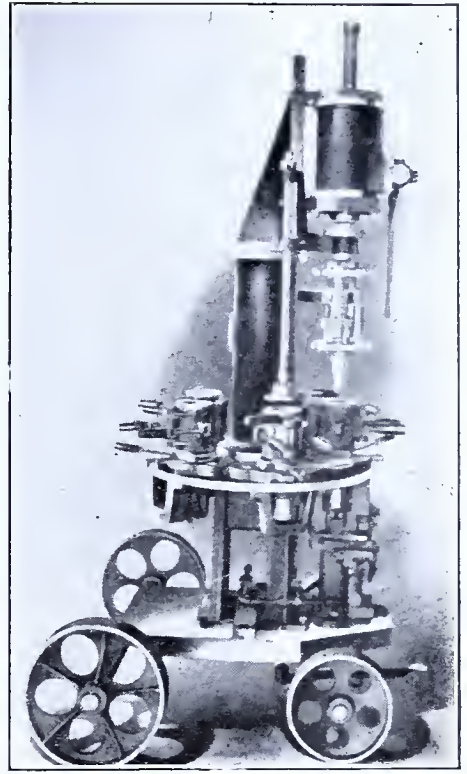
Fig. 2. Semi-automatic pressing
and blowing machine for
wide mouth bottles.
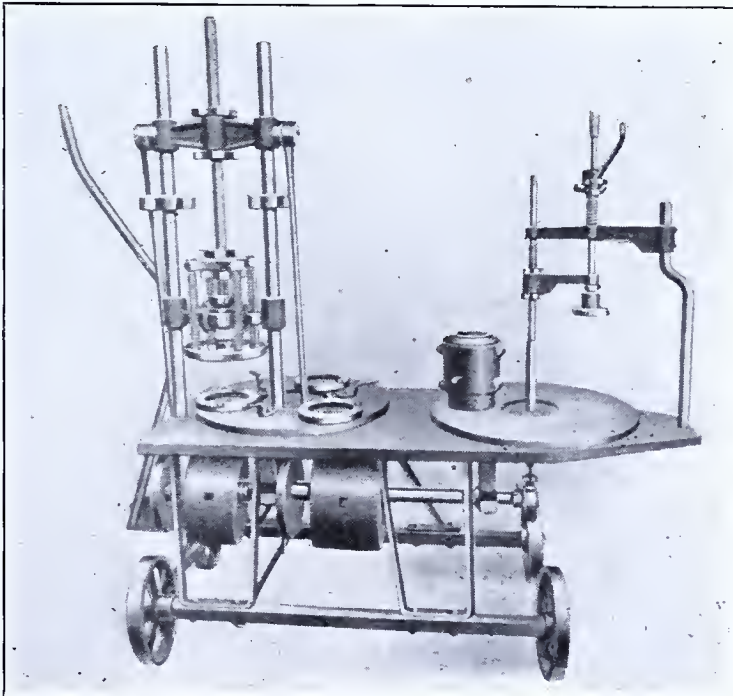
Fig. 3. Pressing and blowing machine for milk jars and
wide mouth ware. (H. L. Dixon Co.)
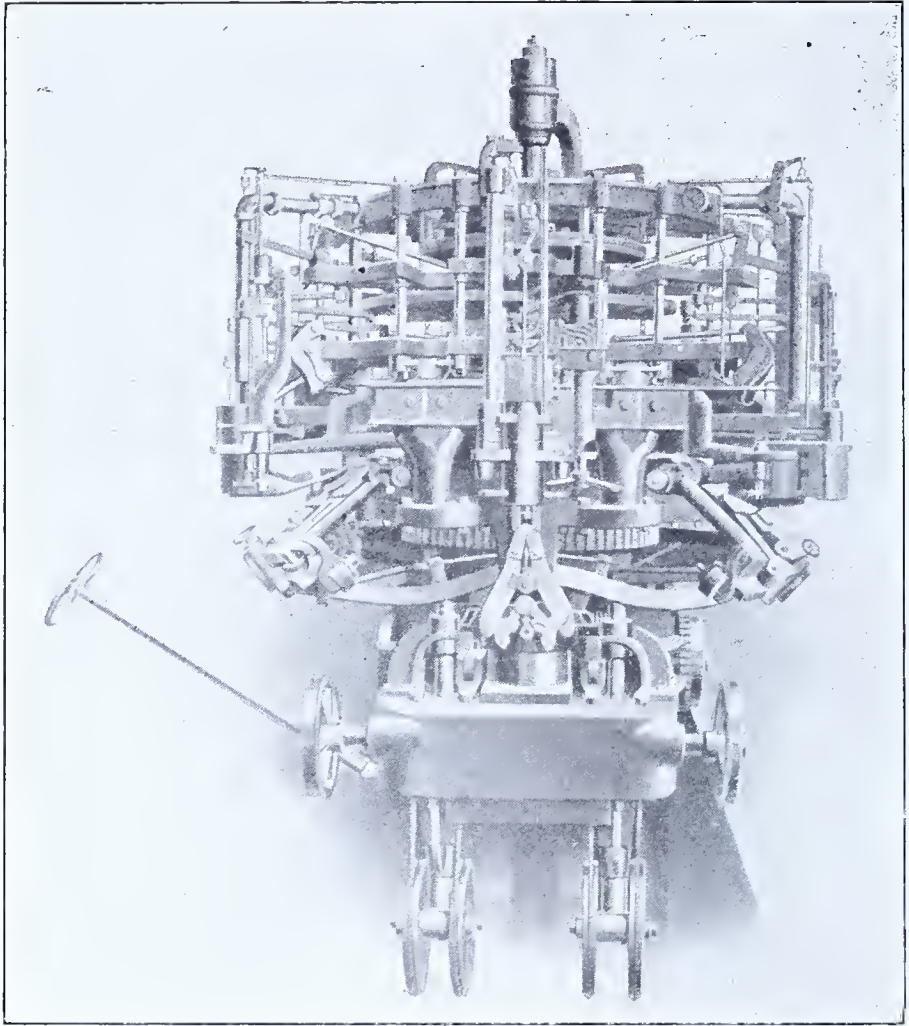
PLATE XLIV.

Owen's automatic gathering and blowing machine.

molten glass from the furnace, shapes the neck and the bottle itself, and turns out a finished product ready for the annealing lehrs, the whole operation requiring practically no attention and going on continuously.

The Owens bottle machine takes the glass from the furnace by dipping a preliminary form into the molten glass, mouth down, and exhausting the air, so that the glass rises in the form. To make the process continuous a number of forms are attached to a revolving device, the rotation of which brings each of these in its turn to the filling station. This brings in the difficulty that each form is brought to the same point to be filled. But the first form plunged into the molten glass cools it sufficient at this point to make it unfit for use for the next form. To overcome this difficulty a furnace with revolving fore-hearth is used.

This fore-hearth consists of a rectangular brick chamber adjoining the tank furnace proper and covering a fan shaped hearth, into which the forms of the machine dip. This pan has a depth of about ten inches, and a diameter of 6½ to 8 feet. It is covered by the brick chamber except where a small strip of the glass surface is exposed by the rounding out of the wall of the covering chamber. The machine is brought up as close as possible to this wall, so that the forms pass over the exposed surface of the glass in their revolution and through the sinking of the machine dip into it. The space above the circular hearth, which has a height of about six feet, is heated by means of burners which can be regulated so as to keep the glass at an uniform temperature. The glass flows from the melting tank proper through a clay trough, with the smallest possible fall, in a slow continuous stream to the circular hearth.

The space underneath this hearth is left open to allow the better cooling of the iron structure underneath. This consists of a platform built of iron supports upon which the bottom of the hearth rests. These supports rest upon cross pieces, with set screws which allow the hearth to be leveled. The cross pieces are supported upon a vertical shaft which rests on a bed of conical rollers on the floor of the plant. The pan is caused to slowly revolve by means of a worm gear attached to this shaft, which is made sufficiently long that the driving gear is kept away from the heat of the furnace.

The hearth makes about two and one-half revolutions per minute, so that every form is dipped into a new place where the glass has not been chilled. The cooled places, and the glass strings falling back at the cutting off of the glass mass from the mould, are again warmed during the revolution of the pan before another mould strikes this particular spot. Inasmuch as the pan and the machine revolve in opposite directions, at the place of dipping the form and the pan travel in the same direction at approximately the same speed. Di-

rectly after the form has been dipped into the glass it begins to fill by suction. At the end of the filling the glass is cut off by a knife which passes underneath the form, and the form is raised and again passes over the edge of the hearth.

The first step in the operation of making a bottle is the dipping of the preliminary form, which is placed underneath the head piece, into the molten glass. The head piece has a mouth stem projecting into it to which a suction pipe is attached. The glass rises up into the preliminary form and head piece and around the stem and is automatically cut off by a knife. Then the form is raised and passes beyond the hearth, the preleminary form separates, leaving the viscous glass hanging free from the head piece, and the final form rises with open halves from below and closes around it. The mouth stem is next withdrawn from the head piece and the bottom form is brought into place. The blowing head is now brought over the head piece and the bottle is blown into shape. The final form and head piece then open and the finished bottle rests free on the bottom form, from which it is thrown into a conveyor trough. Just before the final mould and head piece open the mouth stem sinks a little into the mouth of the bottle so that the bottle, in case it should cling anywhere to the mould, will not fall over.

The whole operation is carried on automatically. The machine itself rests on a truck which can be moved on a track to and from the furnace by its own power. Six or ten sets of forms are arranged symmetrically around a central vertical shaft and are through rotation of this axis brought in turn over the revolving hearth. After the preleminary form has been brought over the hearth it must be dipped into the glass. To accomplish this the whole revolving portion of the machine is lowered. This is done by having it rest in a lowering and raising device, which works automatically. The moulds are kept cool by means of a blast of air from the outside. The inside of the moulds are treated with lubricating oil from time to time. With the larger Owen's machines, which have ten moulds, from 24 to 25 bottles of ordinary size may be turned out in a minute.

In the annealing of bottles the continuous kilns or lehrs have entirely replaced the old style intermittent kilns. Such lehrs are built about 70 feet long and have the first 20 feet heated to a temperature in the neighborhood of 1,000°F., which then gradually drops to that of the atmosphere. The lehrs are run at such a speed that it takes about three hours for the bottles to pass through the lehr.

BLOWN AND PRESSED GLASS.

In the manufacture of hollow glass vessels, such as are used for table ware, lamp chimneys, etc., the process of manufacture are very much similar to those used in the production of bottles, the principal

difference between bottles and the better grades of hollow glassware lying in the composition and quality of the glass used. There are two types of glass used in the manufacture of this kind of glassware, namely, lime-alkali-silicate and lead-alkali-silicate. Soda is the alkali usually employed in the first glass on account of its cheapness. Such glass is often spoken of as lime flint. In the case of Bohemian "Crystal," however, potash is substituted for the soda. In the lead alkali silicate glass, potash is the alkali commonly employed on account of the added brilliancy which it imparts to the glass. This type of glass is usually spoken of as lead flint. The lime flint glasses are made from sand, soda ash or salt cake, and limestone or burnt lime. When salt cake is used some carbon has to be added. A little manganese oxide also is used as a rule to counteract the coloring effects of the small amount of iron present in the sand and other raw materials used. The lead flint glasses are made from sand, potassium carbonate and red lead. Besides these principal constituents, some oxidizing agent, such as nitre, and a decolorizer, such as manganese dioxide, are also added to the batch in most cases. Typical batches for lime and lead flint glasses have already been given· in a previous chapter.

In the better grades of blown and pressed glassware it is important that the raw materials used be as pure as possible with respect to harmful constituents, such as iron oxide. Sands used for this grade of glass, therefore, should not contain over 0.02% ferric oxide. In the manufacture of lead flint glass closed pot furnaces must be employed. For the better grades of lime flint ware these are also used because a glass of·better color can be made in such a furnace than can be produced in a tank furnace. For the poorer grades, however, continuous tank furnaces are frequently used at the present time.

Formerly all hollow glassware was produced by hand. By introducing moulds in which the articles can be blown to the desired shape a part of this hand work has been eliminated. A still later improvement has been the development of machines, very similar to those used in the bottle industry, for blowing the articles into the desired shape by means of compressed air. All of these methods are in use at the present time, although the most primitive of these, in which hand work is employed entirely, is used only in special cases where but a comparatively small number of articles of a particular shape are desired, so that it would not pay to make a special mould for them.

In shaping glass articles by hand the glass blower requires a bench provided with two projecting side rails or arms, across which the blow pipe may be laid in such a position that it can be kept in gentle rotation by rolling it backward and forward. An ordinary blower's

pipe, similar to the one used in making bottles, and a rod to which the glass article upon which work is being done can be attached by means of a little viscous glass taken from the furnace, are employed, as well as a number of different sized and shaped shears and pincers for cutting off, pressing in, and distending the glass. A flat board and a stone or metal plate upon which the glass can be moulded complete the equipment.

The first step in the production of such an article as a tumbler consists in gathering the proper amount of glass on the pipe and blowing it into a small bulb, which is then blown to the proper size and elongnated by gentle swinging the pipe. Then the lower end of this elongnated bulb is flattened by gentle pressing it on the flat plate provided for the purpose. The lower portion of the bulb now has the shape of the finished glass but remains attached to the blow pipe by means of a shoulder and neck. In the hand process the tumbler is next separated from the pipe at the point which leave it of the correct length. An iron rod is then attached to the bottom by means of a little molten glass and the broken edge of the tumbler is held in a flame to round it. The brim of the glass can then be widened or otherwise shaped by rotating it or pressing it in or out by means of a piece of wood. Plate XLV illustrates the various steps necessary in the production of such a tumbler.

Iron moulds are now used almost exclusively in the blowing of such tumblers. These facilitate the operation very much. The glass is gathered on a hollow pipe, blown into a bulb, and after shaping by rolling on a polished plate or by revolving in a hollow iron or wooden block, is blown into the mould and takes its shape. In the case of lamp chimneys, tumblers, and other cylindrical articles, the glass is revolved in the moulds and shows no joint or mould marks. Such moulds are lined with charcoal or special paste which enables the glass to be turned. In the case of lantern globes, or articles with raised or sunken patterns, the glass is blown without turning and takes the exact impression of the mould. Figure 1, Plate XLVI illustrates the blowing and moulding of lantern globes.

The final process in the manufacture of a tumbler after it comes from the mould consists in breaking it from the pipe, well above the shoulder, and annealing it. It then goes to the trimming room where it is cut off at the desired point, either by being heated locally and suddenly by a specially shaped flat blow pipe flame, or by an electrically heated wire. The rough edge is then rounded off, either by the aid of a blow pipe flame or by slightly grinding and polishing the edges. In the case of such articles as lamp chimneys the bottom must also be cut off. A lamp chimney and tumbler are sometimes blown together, the lower portion constituting the tumbler while the upper portion constitutes the lamp chimney.
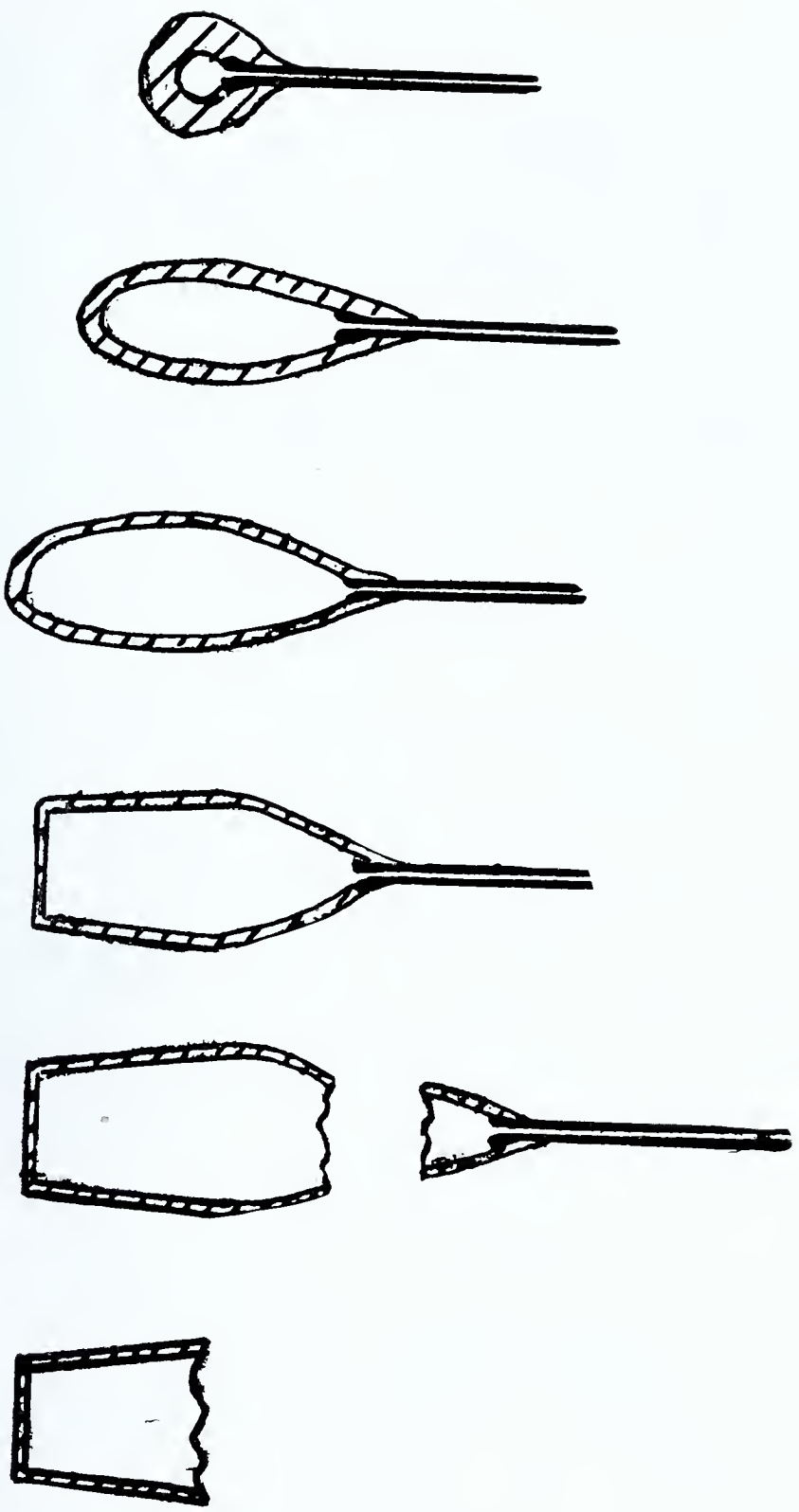
PLATE XLV.

Sectional diagrams showing evolution of a tumbler.

PLATE XLVI.

Fig. 1. Blowing and moulding lantern globes.
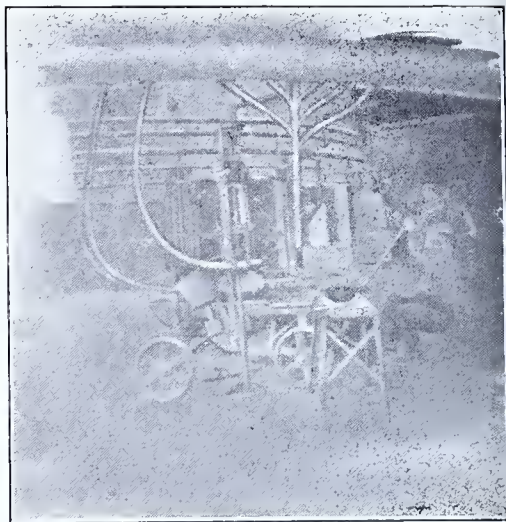
Fig. 2. Pressing a bowl.
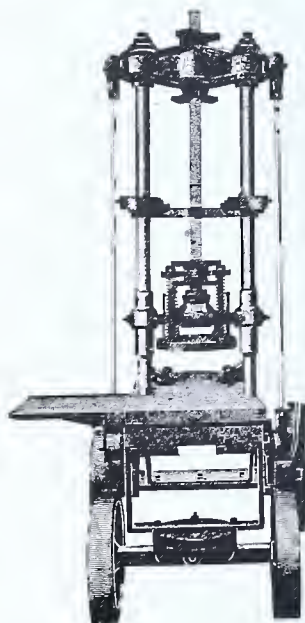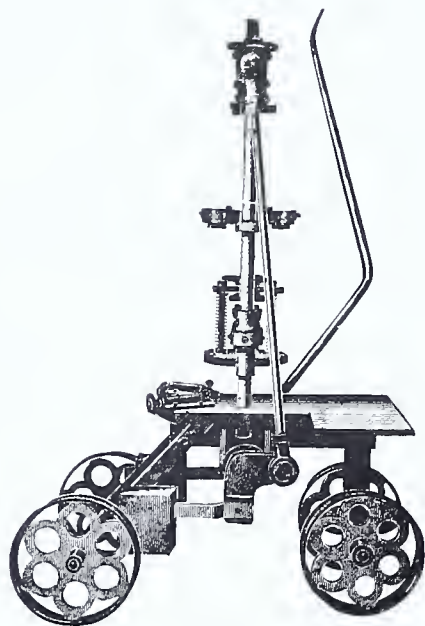
Fig 3. Hand press.

At the present day almost all hollow glassware is blown in moulds. Compressed air has to a great extent replaced the blowers pipe. In the finishing of certain articles pressing in conjunction with blowing is resorted to, as in the case of the bottle industry, and similar machines are employed.

Many glass articles, such as saucers and heavy tumblers, are made by pressing alone. The glass is gathered on the end of an iron rod, by revolving it rapidly in the molten glass. It is then carried to the presser who cuts off with a pair of shears the amount desired and allows it to drop into the mould. A metal plunger is then lowered into the mould and the glass is forced to fill the space between the plunger and the mould. When the glass has become firm the plunger is withdrawn, the mould is opened, and the article is either sent direct to the annealing lehr or is first reheated in an auxiliary furnace or glory-hole to remove mould marks or to alter its shape.

Press moulds are made of cast iron and are constructed in such a manner that the article can be readily removed. The mould and plunger are kept cool by streams of air blown against them. The plunger is usually operated by hand power, but for some purpose steam or compressed air is used. Figure 2, Plate XLVI shows a press in operation, while Figure 3 illustrates the construction of such a press. The moulds are not shown.

Almost all blown and pressed glassware at the present day is annealed in continuous kilns or lehrs. Where the glassware is to be cut and polished afterwards, as in the case of many articles made from lead flint, after it comes from the lehr it is put through a second annealing operation in intermittent kilns of the type already described. This is necessary because it is essential that all internal strain be removed before the glass undergoes the cutting and polishing operation, or it will crack and fly to pieces.

Cut glassware is made from lead flint glass on account of its softness and brilliant lustre. The articles are first given their shape by any one of the processes described above. Often all or part of the raised or sunken patterns on the glass are produced in the moulds. It is then only necessary to go over these lightly in cutting and then to polish them to bring out the brilliant lustre of the glass. In other cases, however, the patterns are cut into the glass entirely, after it has been shaped and annealed. When the articles come from the moulds before they are cut they are known as blanks.

The design is first cut into the glass of the blank by pressing it against an iron wheel fed with sand. The rough surface thus produced is then smoothed on similar wheels dressed with a finer abrasive, and is finally polished by a felt covered wooden bobbin dressed with French "rouge" or putty paste.

In etching or embossing hollow ware hydrofluoric acid is employed.

The portions of the glass to remain unacted upon are covered with a "resist," composed generally of a solution of bitumen and beeswax in turpentine, either by first coating the whole article and then scratching out the portions to be etched, or by applying the "resist" with a brush, or by means of a transfer. The article is then immersed in the acid for a short time, washed, and cleaned. If a weak solution of hydrofluoric acid is used the etched portion is clean and transparent, but if a bath of acid sodium fluoride is used a matte surface is produced.

WINDOW OR SHEET GLASS.

Window glass is made from sand, limestone, salt cake, and a few accessory substances, such as carbon in the form of anthracite coal, or coke, and manganese oxide. Occasionally some soda ash is used to replace part of the salt cake. For window glass the sand employed should not contain more than 0.5% Fe_2O_3. In practice the sand is not always dried, but where wet sand is used determinations of the moisture contents are made from time to time, and allowance is made for this in the preparation of the batch. But even where such determinations are made, in as much as the moisture content is apt to vary considerably even in different parts of the same shipment of sand, (which could only be checked by a large number of determinations), variations in the composition of the batch result which are only permissable in the manufacture of a cheap grade of glass, such as window glass. For the better grades of glass the sand is always dried before using.

Window glass is now prepared almost entirely in continuous tank furnaces of the regenerative type. Tanks up to 113 feet long, 27 feet wide, and 5 feet deep, holding 1,400 tons of molten glass are in use.

Until comparatively recently all window glass was hand made, but now machines have been developed which are gradually replacing the hand labor. In the old hand process the blowers pipe consists of an iron tube, about $4\frac{1}{2}$ feet long, provided at one end with a wooden sleeve or handle and a mouth piece, while the other end is thickened into a substantial cone with a round end. The nose of the pipe is first heated up to the temperature of the molten glass and is then dipped into the glass and turned slightly, once or twice, for the first gathering. This is allowed to cool until it has become fairly stiff, the whole pipe being meanwhile rotated so as to keep the gathering nicely rounded. A small hollow space is formed in the mass of glass through a slight application of air pressure by blowing. As soon as the first gathering has become sufficiently viscous a second one is taken, care being taken that no inclusions of air bubbles result between it and the first one. This is done by gradually rotating the pipe as it is lowered into the
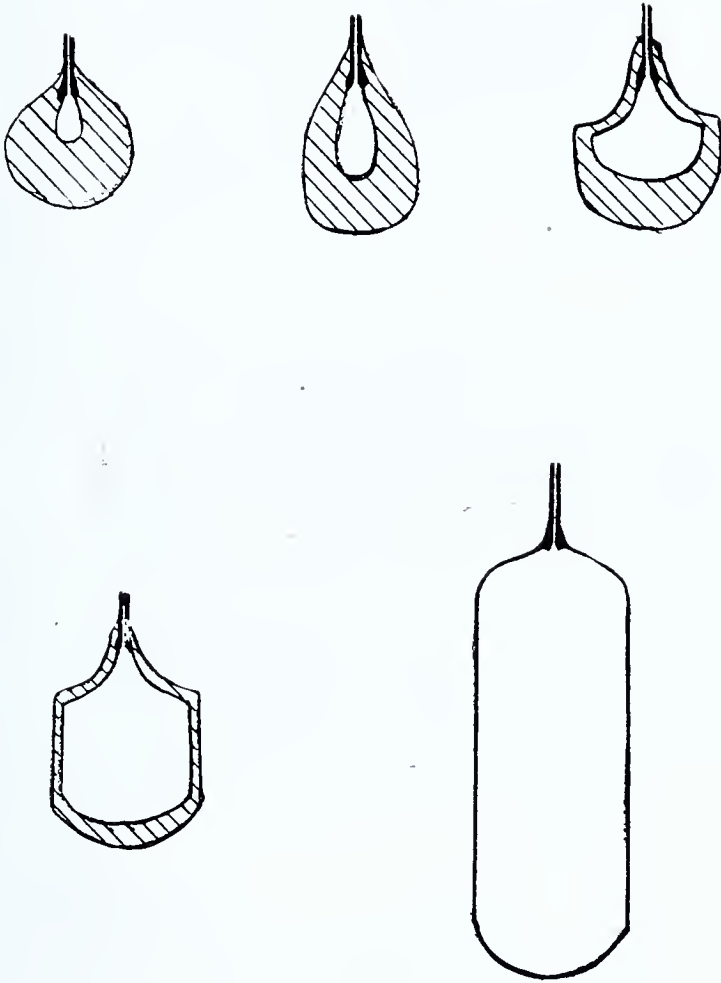
After Rosenhain.

PLATE XLVII.

Sectional diagram showing evolution of a cylinder of window glass.

PLATE XLVIII.
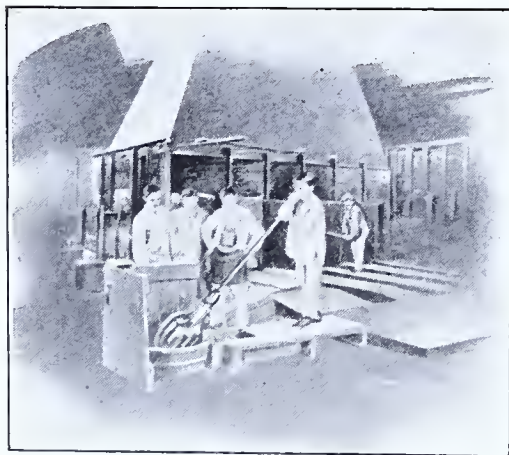
Fig 1. Forming the cap of a cylinder
of window glass.

Fig. 2. Blowing the cylinders.
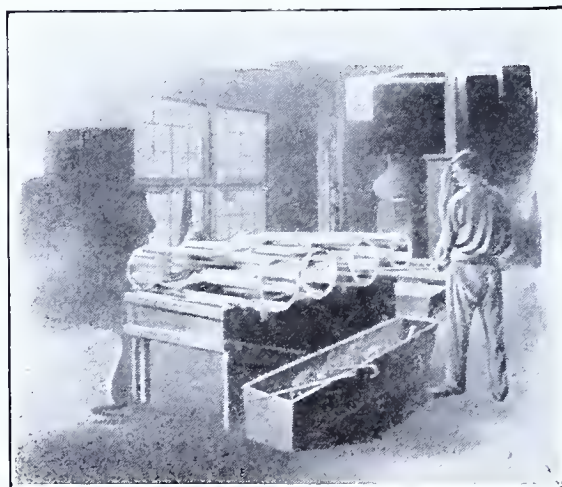
Fig. 3. Cracking open the cylinders.

molten glass.   Three, four to five gatherings are sometimes necessary
to obtain sufficient glass on the end of the pipe.

After the last gathering has been taken up and the mass has cooled
to a working viscosity, the glass forms an approximately spherical
shaped mass, with the nose end of the pipe near its center.   The next
step is to bring the bulk of the glass beyond the end of the pipe and
then to form, just beyond the end of the pipe, a widened shoulder of
thinner and, therefore, colder glass of the diameter required for the
cylinder into which the glass is to be blown.   This is done by the aid of
specially shaped blocks and other instruments in which the glass is
turned and blown.   The final shape attained at this stage is that of
a squat cylinder which has the bulk of the glass at its lower end.
Plate XLVII illustrates the various shapes through which the mass
of glass passes during this operation.

The next step is to blow this mass into a cylinder of equal thick-
ness throughout.   The thick lower end of the cylinder is first held
in a heating furnace until the glass become of the proper viscosity,
and then the pipe is swung with a pendulum movement in the blower's
pit.   The cylinder thus becomes elongnated nnder its own weight
and any tendency to collapse is counteracted by the application of
air pressure from the mouth.   A rotary motion is also given to the
pipe from time to time.   The reheating of the lower portion of the
cylinder is repeated several times until the cylinder has reached an
equal thickness throughout.   Then the rounded end is opened.   The
lower end is heated until it becomes very soft.   The cylinder is with-
drawn from the furnace, held in a vertical downward position in the
blower's pit, and spun very rapidly about its longitudunal axis.   The
glass is thus caused to open out under the centrifugal action and by
increasing the speed of rotation eventually is brought to form a true
continuation of the rest of the cylinder.   It is then allowed to solidify.
Plate XLVIII shows several views in a window glass factory where
the hand process is employed.

The completed cylinder is next placed upon a wooden rack and the
pipe is severed from the cylinder.   After the cylinder has cooled, the
neck and shoulder are removed by passing a wire heated by electricity
around the cylinder at the point where it is to be cut off, and then
applying a cold or moist iron along this heated portion.   As a rule
a crack immediately runs completely around the cylinder along the
line occupied by the wire.   The neck and shoulder of the cylinder
are thus removed and the cylinder is ready to be split.   This is done
on a special stand upon which it is laid in a horizontal position.   The
splitting is done by drawing a heavy diamond skillfully down the
length of the cylinder on the inside.   A hot iron, followed by moist-
ening, is sometimes used for the same purpose.

After the cylinder has been split it is ready to be flattened and annealed. For this purpose the cylinder is first taken to a special kiln, or flattening oven, where they are heated to a dull red heat. They are then lifted, one at a time, onto a smooth fire clay tile and flattened and polished with a wooden block on the end of a long handle. From there the flattened sheets go to a continuous annealing kiln or lehr, which has already been described in the chapter on annealing. The flattening ovens and lehrs are usually built together. The split cylinders are placed into a short, tunnel shaped, heated kiln, through which they are slowly conveyed to a large revolving circular table, carrying four flattening tiles, one in each quadrant. In the kiln they are heated up to the necessary temperature for flattening. The cylinder then drops onto a tile on the flattening table, is carried to the front of the furnace where a man flattens it through a large opening by means of a wooden block attached to a long handle and it then continues around to the lehr, where another man through a second opening, lifts it onto the rods of the lehr conveyor. After the glass comes from the annealing lehr the sheets are examined for defects, sorted, cut and trimmed to the desired shape, and packed for shipment.

"Ground glass" is prepared by abraiding the surface of the glass by impinging a stream of fine sand upon it by means of a powerful air blast. This renders the surface of the glass rough and opaque. Any desired design may be produced upon it by protecting portions of the surface by means of metal stencil plates. When glass is to be frosted it is first sand blasted and then coated with a hot solution of hard glue, several coats being applied. It is then placed in a warm chamber, where the force exerted by the contraction of the glue on drying tears away the surface of the glass in a peculiar manner, giving it the appearance of a frosted window pane.

What the Owen's bottle machine has done for the bottle industry, the Lubber's cylinder drawing machine has accomplished for the window glass industry. Machine made window glass has through the advent of this machine largely replaced the hand made glass. In using this machine the glass is first ladled from the furnace into a flat, shallow clay pot. These pot are made double, so that while one is full of glass the other one is in an inverted position underneath, thus allowing the glass adhering to the sides to flow out under the heat of burners placed beneath it for this purpose. The glass cylinders are drawn from these pots. A large blow pipe is immersed into the molten glass, compressed air is introduced, and the blow pipe is gradually withdrawn from the molten glass. By carefully regulating the speed of the withdrawal and the amount of air introduced cylinders of uniform diameter and thickness of glass can be made.

The factors which determine the diameter of the cylinder and thick-
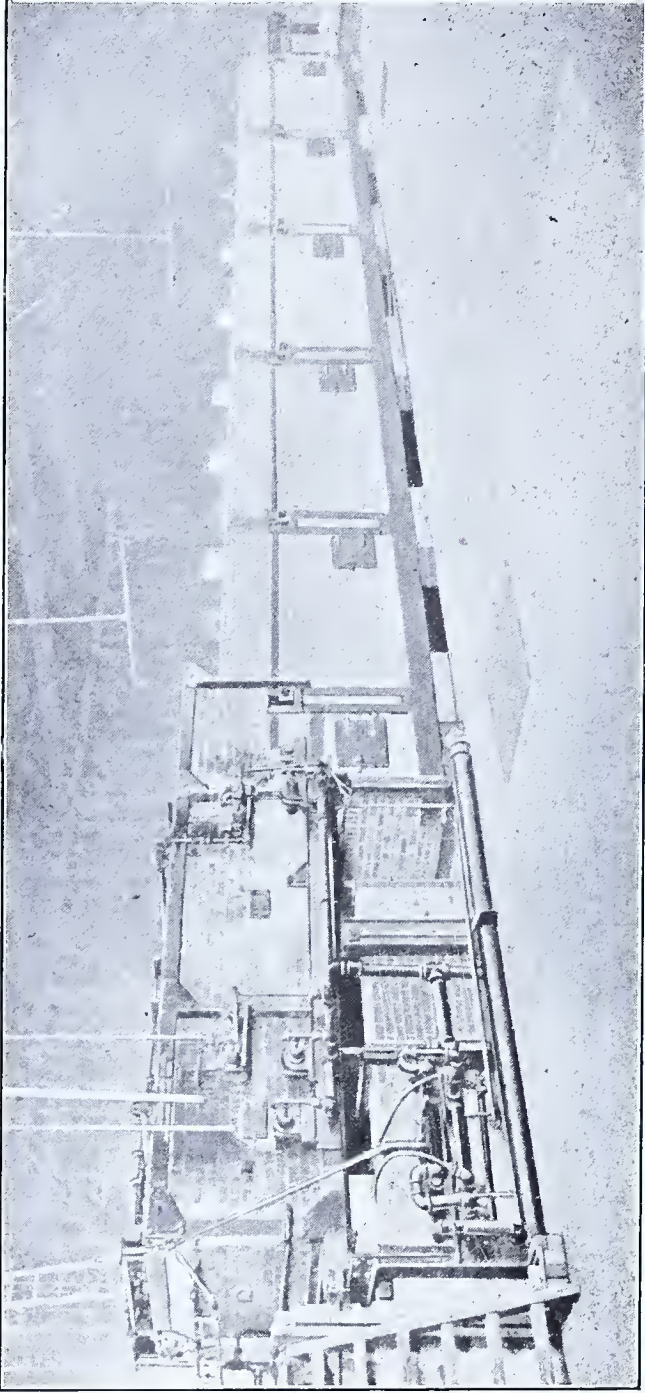
PLATE XLIX.

The Colburn Window Glass Drawing Machine and Annealing Lehr. (H. L. Dixon Co.)

ness of the glass are the pressure of the surrounding air, the rapidity with which the cylinder is withdrawn, and the temperature of the glass. It is necessary to have the pressure inside of the cylinders a little higher than the surrounding air, or a cylindrical shape will not be maintained. As the air gradually cools in the cylinder more air must be admitted. Air must also be admitted to occupy the new space inside the gradually enlarging cylinder. For these reasons there must be a slow increase in the rate of admitting the air. This is controlled automatically. The speed of withdrawal of the cylinder has to be gradually increased also, on account of the slow cooling of the glass. This is done by having a pulley with a conical or tapering face, thus making its diameter increase as the operation proceeds, upon which the cable which raises the blow pipe and cylinder is wound. The temperature of the glass has an important bearing on the thickness, the glass becoming thicker as the temperature becomes cooler. Cylinders 20 to 24 feet long and 30 inches in diameter can be made with these machines. The trimming, splitting, flattening and annealing are conducted in a manner similar to that used in the hand process.

Other types of window glass machine have been developed, though hardly beyond the experimental stage, in which continuous sheets of glass are drawn from the furnace. Plate XLIX shows the outer appearance of a glass drawing machine of this type.

ROLLED OR PLATE GLASS.

Ordinarily when the term plate glass is mentioned, polished plate is referred to, but there is another type known as rough "rolled plate," used for skylights, etc., that is also made by being rolled out into a sheet on a metal plate. Rough rolled plate is a cheap type of glass and is only used where appearance is not considered an important factor, the chief requirement being cheapness. The color is only of importance in so far as it affects the quantity and character of the light which it admits to the building. Sand, salt cake, and limestone are the chief raw materials used, together with the addition of carbon in the form of anthracite coal, coke or charcoal, and usually some clarifying and decoloring agents. Sands similar to those used for window glass may be employed for rough rolled plate.

Continuous tank furnaces are employed to melt the glass. Since the cheapest glass batches to prepare are those poor in alkalies and high in lime this type of glass has comparatively high melting point, and the furnaces must be constructed so as to be able to work at high temperatures. Otherwise the construction of the furnace is very simple, as no requirements for regulating the temperature of the various parts in order to insure perfect fining of the glass are required, because absolute freedom from enclosed gas bubbles is not necessary.

The furnace, therefore, generally consists simply of a rectangular tank, into one end of which the raw materials are fed, while the glass is withdrawn by means of iron ladles from one or two suitable openings at the other end. The size of the ladle used depends on the size of the sheet to be cast, the object being to have just the amount of glass for the sheet to be rolled. Sometimes ladles carrying as much as two hundred pounds of glass are used for large sheets. They are suspended from slings that run on an overhead rail.

The rolling table used in the manufacture of rolled plates consists essentially of a cast iron slab of the proper size to accommodate the largest sheet to be rolled. A massive iron roller is moved over this slab, driven either by hand or mechanical power, usually the latter. The thickness of the sheet to be rolled is regulated by means of strips of iron placed at the sides of the table, in such a way as to prevent the roller from descending any further towards the surface of the table. So long as the glass is thicker than these strips the entire weight of the roller rests on the glass and presses it down until the requisite thickness is attained and the weight of the roller is taken by the iron strips. The width of the glass is regulated by means of a pair of guides, formed to fit the forward face of the roller and the surface of the table. The roller pushes these guides ahead of it and the glass is confined between them. When the sheet of glass has been rolled out it is left on the table until it has cooled and hardened sufficiently to be safely moved. Plate L shows two types of casting tables.

The sheet is next moved to the annealing kiln or lehr by being drawn onto a stone slab and pushed into the mouth of the kiln. This kiln consists essentially of a long, low tunnel, heated at one end and cool at the other, the temperature decreasing gradually and uniformly between the hot and cold ends. The sheets slowly pass down this tunnel and are gradually cooled and annealed. They are moved down the tunnel by a series of rods similar to the Tondeur rod system used in window glass annealing lehrs. Ordinarily the sheets lie flat on the floor of the kiln tunnel. Their movement is effected by a system of moving grids which run longitudinally down the tunnel and can be lowered into recesses cut in the floor for them. At regular intervals the iron grid bars are raised sufficiently to just lift the sheets from the bed of the kiln, and are then moved longitudunally down the kiln a short distance, carrying the sheets forward with them, and again depositing them on the floor of the kiln. The grids return to their former position while lowered into their recesses below the level of the kiln bed.

After coming from the annealing lehr the sheets of rolled plate glass are taken to the cutting and sorting rooms where they are classified and trimmed to the desired shape and size ready for the market.
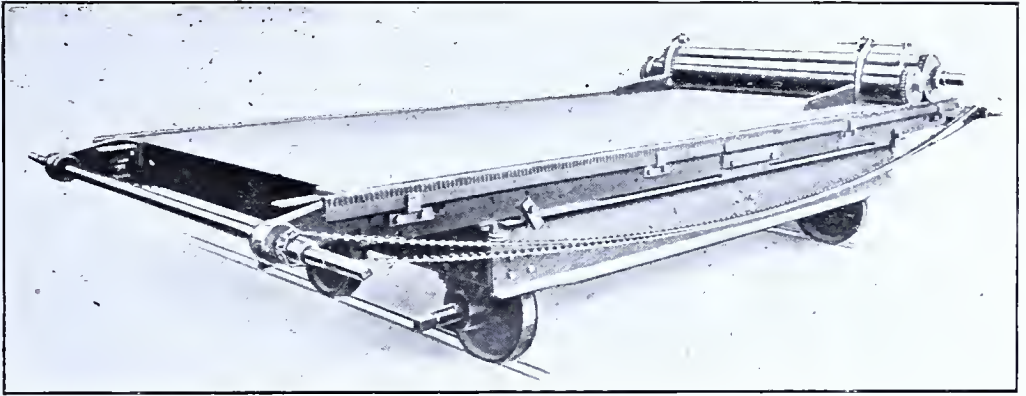
PLATE L.

Fig. 1.   Casting table.   (H. L. Dixon Co.)
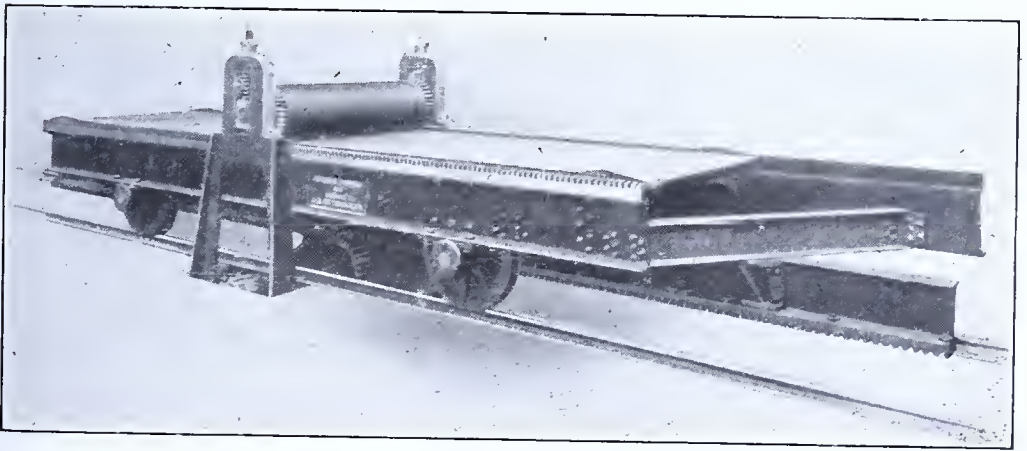
Fig 2.   Electrically driven Glass Casting Machine for Rolling Ribbed or Figured Glass.   (Rosedale Foundry and Machine Co.)

PLATE LI.
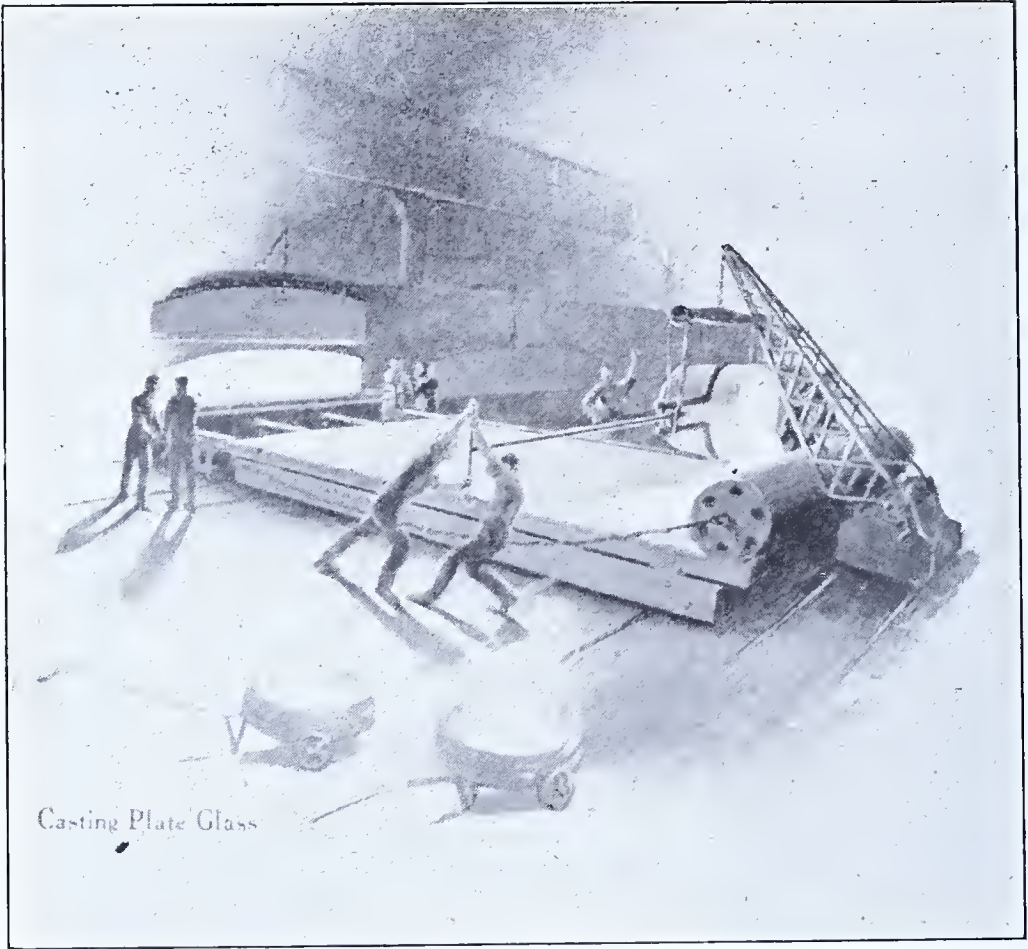
Fig 1. Casting plate glass.
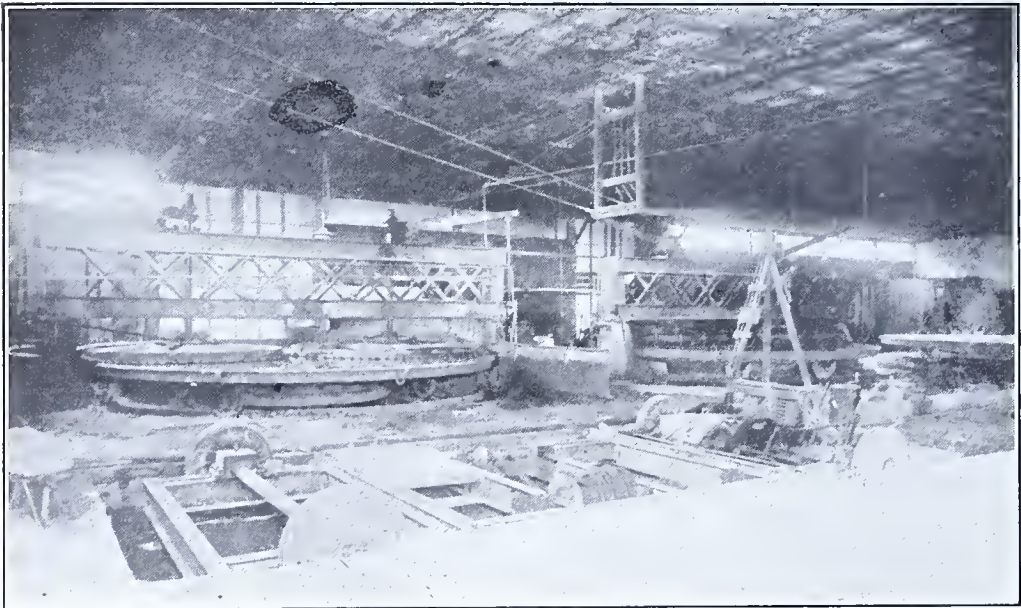
Fig. 2. View in a glass grinding and polishing plant.

Polished plate glass requires much greater care in the selection of raw materials than does either window glass or rough rolled plate. Color is an item of considerable importance on account of the greater thickness of the plate glass as compared with window glass, which makes slight shades of color much more pronounced than in the thinner glass. It is made from sand, limestone, and salt cake, together with some soda ash. Carbon in the form of coke or coal has to be added to the batch to help reduce the salt cake, and some clarifying and decoloring agents are also as a rule employed. Batches for plate glass have already been given in a previous chapter. The sand used for ordinary plate glass should not contain more than 0.2% Fe_2O_3 and where it is used in making mirrors not more than 0.1%.

The glass is melted in large open pots, varying in diameter from 38 to 52 inches. The larger ones weigh up to 2,400 pounds and hold 2800 pounds of molten glass. Twenty pots are usually placed in a furnace, ten on a side, as has already been described. The furnaces are heated up to temperatures of about 2800°F. Care is required to insure perfect melting and fining, since even minute defects are readily visible in plate glass, and detract seriously from its value. The pots usually have to be filled three times with batch before they contain a sufficient charge of glass. About twenty-four hours are required to melt and fine the glass in each pot.

When the glass in a pot is ready to be cast the furnace door in front of the pot is raised and the pot is withdrawn from the furnace and carried by means of an overhead crane to the casting table. To facilitate this operation the pots are provided with projections on their outer surface by which they can be held in suitable shaped tongs or cradles. Before the pot is poured it has to be carefully skimmed to remove the glass "gall" which collects on top of the molten glass. When the pot has been brought into position over the rolling table, it is tilted and the glass is poured out in a steady stream upon the table, care being taken to avoid the inclusion of air bubbles during this operation. As soon as the pot is empty it is returned to the furnace as rapidly as possible to avoid excessive cooling.

The casting table consists of a large, massive, flat table of iron, having as an attachment a heavy iron roller which has a length equal to the full width of the table. The sides of the table are fitted with adjustable strips which permit the producing of plates of different thicknesses. As the half fluid glass is poured onto the table from the melting pot, the roller quickly passes over it and rolls it out into a sheet of uniform thickness. The heavy roller is then moved out of the way and by means of a stowing tool the red hot plate is shoved into an annealing oven. Figure 1, Plate LI shows the method of casting a plate of glass.

At the present time there is a tendency to introduce continuous kilns or lehrs for annealing plate glass, although many plants still use the intermittent type of kiln. The difficulties with the continuous lehrs have been to devise mechanical means to handle sheets of glass as large as those frequently rolled in the plate glass industry in such a manner as to prevent them from warping, and to design such type of lehr that the temperature would drop sufficiently uniformly from one end to the other to insure perfect annealing of the glass, so that the plates would be able to stand the rough usage of grinding, polishing, etc., to which they are later subjected. These difficulties have now been practically overcome so that continuous lehrs are used in some factories. A modification of the Tondeur rod lehr system has been adopted for handling plate glass in continuous kilns which work admirably for plate up to two hundred square feet in size. Intermittent kilns for plate glass have already been discussed in the chapter on annealing. One kiln is usually provided for each casting table, so that the glass may be shoved from the table directly into the kiln, the floor of the latter being on the same level as the top of the table. The plates remain in these kilns for several days, while the temperature gradually drops to that of the atmosphere.

When the plate comes from the annealing oven it has a rough, opaque, almost undulating appearance on the surface, although the inside is perfectly clear. It is first inspected carefully so that bubbles or other defects may be marked for cutting out. It then goes to the cutter who takes off the rough edges and squares it into the right dimensions. After this has been done it is ready for the grinding rooms.

The process of grinding and polishing plate glass consists essentially of three steps. First, the surface of the glass is ground so as to make it as perfectly flat as possible. A coarse abrasive is used for this purpose which leaves the glass with a rough, gray, surface. The second step consists in grinding this rough, gray surface by means of a finer abrasive until it becomes as smooth as possible. The gray surface is still retained. This is removed in the final process of polishing with rouge, by means of which a brilliant, clean surface is produced.

The grinding is done on large, flat, revolving platforms or tables made of iron, and usually twenty-five or more feet in diameter. The grinding table is prepared by being flooded with plaster of Paris and water. The glass plates are carefully fitted and lowered upon this surface and tramped into place until the plaster has set. After this greater security is obtained by pegging them with wooden pins, and then the table is set in motion. The grinding is done by revolving runners. The runners consist of iron slabs or wooden boxes shod with iron, but much smaller in diameter than the grinding table.

These runners also rotate about a central vertical axis, being set in motion either by the frictional drive of the revolving table under them, or by the action of an independent driving mechanism.

Sharp sand is first fed upon the table and a stream of water constantly flows over it. An attempt is usually made to roughly classify the sand, the coarser being first fed and then finer and finer. The final grinding is done by means of emery. Figure 2, Plate LI shows a view taken in the grinding room of a plate glass factory. After one side of the plate has been ground down to a smooth, gray surface, the plates are taken up, turned over, and the other side is ground in a similar manner. After the plates have two smooth, parallel, gray surfaces, they are ready to be polished. This is usually done on another special table. Rouge, a variety of finely pulverized iron oxide, applied with water is the polishing medium used. The rubbing is done by blocks covered with felt. Reciprocating machinery is so arranged that every part of the plate is brought underneath the rubbing surface. After the glass has been polished it is sorted, classified into several grades, and cut to the desired sizes, ready for shipping.

Wire glass is rolled plate glass in which during the rolling process wire has been imbedded, which adds to its strength and prevent it from flying to pieces when cracked. It is used to considerable extent in fire proof construction for this reason. This type of glass is usually made by rolling a sheet half the thickness of the final sheet, placing the wire mesh on this and then rolling another layer of glass on top of it. Two difficulties are encountered in the manufacture of wire glass. The most serious one of these is the difference in thermal expansion of the glass and the wire. As glass and wire cool down from the heated condition, the wire contracts considerably more than the glass, and breakage results either immediately, or the glass is left in a condition of severe strain and is apt to crack spontaneously afterwards. The second difficulty lies in the fact that most metals when heated give off considerable quantities of gas, and when this gas is evolved after the wire has been imbedded in the glass, numerous bubbles are formed which not only render the glass unsightly but also lessen the adhesion between the wire and the glass. This difficulty can usually be overcome by keeping the wire clean and expelling all gas from it by preliminary heating.

OPTICAL GLASS.

In the production of optical glasses the kinds and relative proportions of the raw materials used depends upon the chemical composition of the particular glass desired. A glass of such chemical composition is produced as has been shown by previous experiments to possess the optical properties desired. Extreme care has to be exer-

cised so that only such raw materials are used as possess the greatest possible chemical purity and these must be thoroughly mixed, since optical glass must be absolutely homogeneous. In order to make this mixing more nearly perfect the raw materials are usually employed in a more finely divided state than in the case of the ordinary varieties of glass. A little "cullet" or broken glass from previous meltings is usually added to the batch. This must have the same chemical composition as the glass which is being produced.

Optical glass is made in covered pots. The pot furnaces differ from the ordinary type in that each furnace holds but one pot, so that the time and temperature of the melting operation can be carefully regulated for each individual fusion, this extreme care being necessary in the manufacture of optical glasses. In addition to the pot furnaces kilns are also required for the preliminary heating and the final cooling of the pots. The pots employed for this purpose have thinner walls than those used for flint glass and the fire clay from which they are made has to be even more carefully selected, so there will be no contamination of the glass by iron or other impurities from the walls of the pot.

The covered pot is first carefully dried, as in the case of flint glass pots. It is then placed in one of the preliminary heating kilns and the temperature is gradually raised over a period of four or five days to a red heat. In the mean time the pot furnace has also been brought up to about the same temperature. The pot is transferred to it as rapidly as possible, so as to reduce the amount of cooling to a minimum. The melting furnace is then sealed up by a temporary brickwork, leaving only the mouth of the pot's hood accessible. It is heated five or six hours longer until the melting temperature of the glass is reached. Then pieces of cullet, from previous meltings of the same chemical composition, are charged into the pot and the bottom and sides of the pot are glazed with this glass by means of a large iron ladle. This is done to prevent the raw materials attacking the walls of the pot during the early stages of the melting operation.

As soon as the pot has been thus glazed it is ready to receive the first charge of batch. The raw materials are introduced a little at a time, a fresh layer being added as soon as the previous one has melted. This is kept up until the pot contains the requisite amount of molten glass. The charge cannot all be introduced at once, because it occupies more space than the resulting glass, and also because it froths considerably during the early stages of melting. If too much material is added in one charge an overflow of half melted glass is apt to occur through the mouth of the pot.

As soon as the batch has all been thoroughly fused, the glass is ready for the "fining" process. To accomplish this the temperature

of the furnace is raised. This allows the glass to become more fluid and also causes the bubbles of gas to expand, both of which facilitate their escape. This temperature is maintained until the glass is entirely free from bubbles, which takes anywhere from six to eight, and in some cases even thirty hours. Great care and considerable experience are required during the "fining" to maintain the right temperature. If it is too low the bubbles will not rise, while if it is raised too high the glass may attack the pot and dissolve some of the clay.

When the "fining" operation has been completed the temperature is allowed to drop somewhat and all scum which has collected on the surface of the glass is carefully removed. The glass is now ready for the stirring operation, which is necessary to render it perfectly homogenous and free from striae. A stirrer consists of a hollow fire clay cylinder, 4 to $4\frac{3}{4}$ inches in diameter, provided with a deep square hole at the upper end, into which a small iron bar passes. This clay cylinder is first raised to a red heat and is then dipped into the molten glass by means of the iron bar. It is left in this position for an hour or so to allow the bubbles forming on it to escape to the surface. The stirring consists in holding the cylinder in a vertical position and giving it a rotary motion by means of the bar attached to its upper end. From four to twenty hours are required for this operation. The stirrer is then removed. By this time the glass has become sufficiently cooled that the stirrer can only be moved in it with difficulty. The pot is next lifted out of the furnace and placed on a fire brick platform where it is allowed to cool freely for half to three quarters of an hour. This causes it to solidify comparatively rapidly and prevents any aggregation of heavier and lighter parts to occur.

When the glass has been chilled down to a certain point, however, this rapidity of cooling must be arrested, or the whole contents of the pot will crack and splinter into minute fragments. It is, therefore, taken to the annealing furnace, where during the next three days, or so, the mass is allowed to cool down slowly to ordinary temperatures. As soon as this has taken place the pot is drawn out and the fire clay shell, which is generally found cracked into many pieces, is broken away from the glass, which is usually found to be more or less fissured, a number of large pieces being accompanied by a large mass of small fragments. These are carefully sorted and all those which are free from visible imperfections, or can be readily detached from such defects by the aid of chipping hammers, are laid to one side for further treatment.

These rough broken lumps are next moulded into the shape of plates, blocks, or discs, depending upon the use to which they are to be put by the optician. To accomplish this the glass is reheated in moulds

until it almost melts. This is done in a long, tunnel shaped furnace which is heated to a red heat at one end while the other end is just cool enough to allow the moulds to be pushed in. After the glass has been moulded to the desired shape it is placed in the final annealing kiln where it is cooled for ten to twelve days. When cool the glass is polished on both sides and carefully examined for any remaining defects. These pieces of glass are now termed blanks, and are ready to be cut into lenses and other optical ware. The yield from each pot usually amount to only ten to twelve per cent of the total glass melted in the pot, twenty per cent being considered a very satisfactory production.

When large lenses are made, in which absolute freedom from stress acquired in cooling is necessary, the final annealing must be carried out with extreme care. A special type of annealing oven has been designed for this purpose in which the source of heat, the temperature, and the rate of cooling can be automatically controlled. This consists of a very thick, cylindrical shaped copper vessel, on which a large gas flame plays. The glass is placed inside of this cylinder. The temperature of the interior is measured by means of the pressure of mercury vapor, which is balanced by a column of mercury in an open tube, whose heights regulates the flame. It has been found that the highest temperature necessary to make all stress vanish is 465°C., while the lowest temperature required to insure complete hardening is about 370°C. The fall of 95° is spread over an interval of four weeks by means of this annealing device.

$30,000,000

20,000,000

Pennsylvania.

Ohio

Indiana

10,000,000

Pennsylvania

West Virginia
New Jersey

5,000,000

Illinois
New York.

New Jersey
New York
Ohio
Illinois,
Indiana
West Virginia

1880   1900   1910
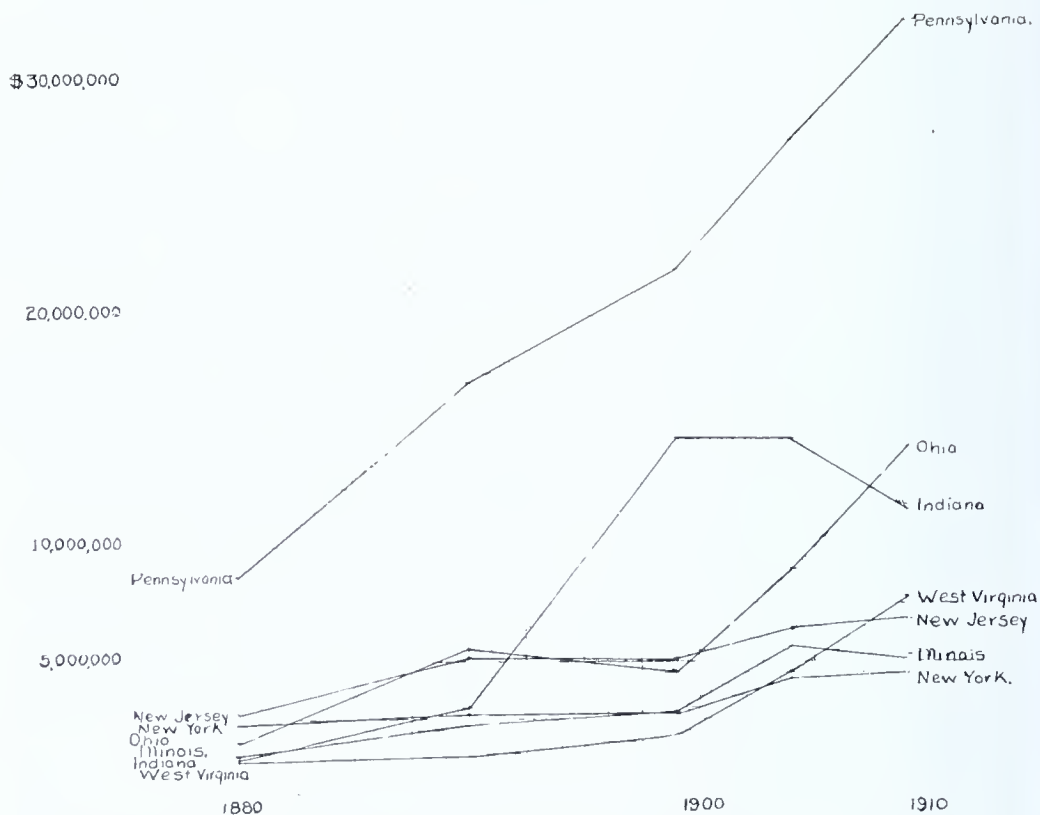
PLATE LII.

Diagram showing value of glass production of seven leading states from 1880
to 1909. Compiled from United States Census Reports.

CHAPTER XII.

STATISTICS OF THE GLASS INDUSTRY IN PENNSYLVANIA.

(Taken from Reports of the United States Census.)

Table 1.

Value of Glass Produced in the United States.

State.	1909.	1904.	1899.	1890.	1886.
Pennsylvania,	$32,817,936	$27,617,693	$22,011,130	$17,179,137	$8,720,584
Ohio,	14,358,274	9,026,208	4,457,083	5,649,182	1,549,320
Indiana,	11,593,094	14,706,929	14,757,883	2,995,409	790,781
West Virginia,	7,779,483	4,598,563	1,871,795	945,234	748,500
New Jersey,	6,961,088	6,450,195	5,093,822	5,218,152	2,810,170
Illinois,	5,047,333	5,619,740	2,834,398	2,372,011	901,343
New York,	4,508,790	4,279,766	2,756,978	2,723,019	2,420,796
Kansas,	2,036,573	958,720	*	*	*
Missouri,	1,992,883	1,781,026	765,564	1,215,329	919,827
Maryland,	1,038,368	589,489	557,895	1,256,697	587,000
Virginia,	681,900	549,031	*	*	*
All other states,	3,279,481	3,376,538	1,343,164	1,496,834	1,706,250
United States,	$92,095,203	$79,607,998	$56,539,712	$41,051,004	$21,154,571

*No figures available.

The above table shows that Pennsylvania is by far the most important glass producing State in the Union, having in 1909 produced 35.6% of the total output of glass in the country. Its rank in this respect as compared with other glass producing states is better brought out by the production diagram shown in Plate LII. Western Pennsylvania has become the great center of the glass industry in this country on account of the large supplies of cheap fuel, both coal and natural gas, which it possesses, and on account of its proximity to the important markets for glass. Another factor of perhaps somewhat less importance is the large deposits of glass sands which occur in the State. The location of the different glass plants in operation in 1914 in Pennsylvania are shown on the map of the State accompanying this report.

Table 2.

Value of Glass Production in Pennsylvania in 1909 by Varieties.

Building glass (plate and window),	$14,958,649
Pressed and blown glass,	9,847,228
Bottles and jars,	7,778,787
Other varieties not included in above,	233,272
Total,	$32,817,936

Table 3.

Statistics of the Glass Industry in Pennsylvania in 1909.

Number of establishments,	112
Persons engaged in the industry (total),	24,924
Proprietors and firm members,	34
Salaried employes,	1,180
Wage earners (average number),	23,710
Capital invested,	$58,632,000
Salaries paid,	1,730,000
Wages paid,	13,436,000
Cost of materials used,	12,634,000
Value of products,	$32,817.936

Table 4.

Pot and Tank Furnaces in the United States and in Pennsylvania in 1909.

	In Operation.	Idle.
United States,	370 pot furnaces (4945 pots) 369 continuous tanks (3759 rings) 73 intermittent tanks (433 tons capacity)	59 pot furnaces (697 pots) 48 continuous tanks (436 rings) 13 intermittent tanks (56 tons capacity)
Pennsylvania,	144 pot furnaces (2,086 pots) 99 continuous tanks (1178 rings) 26 intermittent tanks (145 tons capacity)	23 pot furnaces (301 pots) 12 continuous tanks (93 rings) 6 intermittent tanks (27 tons capacity)

CHAPTER XIII.

Introduction.

In the annual production of glass sand Pennsylvania ranks as the leading state. In 1914 there were 512,718 tons of glass sand produced, valued at $611.173.[35] This was 32% of the total tonnage and 39% of the total value of the glass sand produced in the United States during that year. In 1915 the production was 455,512 tons, valued at $550,706, as reported by operators to the United States Geological Survey.

Pennsylvania holds this important position for two reasons. One is that excellent deposits of pure quartz sandstone suitable for crushing into glass sand are available in various parts of the State, and the other is that the western part of the State offers an excellent market for such sands, as a large portion of the glass factories of the United States are there located, for economic reasons already discussed in a previous chapter.

Location of the Industry.

At present the glass sand industry is practically confined to two parts of the State, namely: the central portion, and the western part. Of these the central area is by far the most important, both as regards the total tonnage of glass sand produced and its better quality for glass making. The productive area is confined to several localities in Huntingdon and Mifflin counties, in the vicinity of Mapleton, Vineyard, and Granville along the main line of the Pennsylvania Railroad, between Huntingdon and Lewistown. In the western part of the State the workable deposits are distributed over a much greater area, but the quality of the sandstone available is not as good as that of central Pennsylvania. In this region glass sand quarries are being operated in Elk, Fayette, Forest, Jefferson, Venango, Warren and Westmoreland counties.

Formations Involved.

Deposits of sand and sandstone of sufficient purity to be suitable for glass sand occur in several of the geological formations present in Pennsylvania. For the benefit of those who are not familiar with the various eras and periods into which geologic time has been divided the following table, taken from Chamberlin and Salisbury's Textbook of Geology, will probably make this part of the discusion more in-

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35. Mineral Resources of the United States, Part II, Non-Metals, 1914. U. S. Geological Survey, p. 278.

telligible. The different periods are given in their order, beginning with the most recent.

Eras.	Periods.		
Cenozoic,	Quaternary,	Human or Recent. Pleistocene or Glacial.	
	Tertiary,	Pliocene. Miocene. Oligocene. Eocene.	
Mesozoic,		Cretaceous. Comanchian. Jurassic. Triassic.	
Paleozoic,		Permian. Pennsylvanian. Mississippian. Devonian. Silurian. Ordovician. Cambrian.	

Proterozoic.
Archeozoic.

The glass sands of central Pennsylvania are derived from the Oriskany formation, which is one of the formations deposited over this portion of Pennsylvania during Lower Devonian time. Those of the western part of the State come from the Pottsville formation, the lowest member of the Pennsylvanian in this State. Quarternary deposits along certain of the river valleys of southwestern Pennsylvania were at one time made use of in the manufacture of cheap grades of glass, but with the extensive exploitation of the better grade of sand derived from the Pottsville, and the practical exhaustion of the valley deposits, they are not longer of economic importance. There are, therefore, at the present time only two formations, the Oriskany and the Pottsville, that are the source of all the glass sand produced in the State. Of these the Oriskany is the most important.

CHAPTER XIV.

THE ORISKANY FORMATION.

At its type locality in Oneida county, at Oriskany Falls, in central New York, the Oriskany formation has a thickness of about twenty feet, and consists of nearly pure, white, fossiliferous quartz sand rock. It differs considerably, however, both in composition and in thickness over the large area in which its outcrops occur in the eastern part of the United States, the composition ranging all the way from a practically pure quartz sandstone to a siliceous limestone, with thicknesses varying from a few inches up to several hundred feet.

Character and Distribution of the Oriskany Formation.

The succession of Silurian and Devonian formations as they occur in New York, and the position of the Oriskay among them, is shown in the following table taken from Handbook 19, of the New York State Museum:

Devonian,	Chautauquan,	Chemung beds.	
		Catskill sandstone.	
	Senecan,	Portage beds.	
		Naples beds.	
		Ithica beds.	local facies.
		Oneonta beds.	
		Genesee beds.	
		Tully limestone.	
	Erian,	Hamilton beds.	
		Marcellus beds.	
	Ulsterian,	Onondaga limestone.	
		Schoharie grit.	
	Oriskanian,	Esopus grit.	
		Oriskany sandstone.	
		Port Ewen limestone.	
	Helderbergian,	Beeraft limestone.	
		New Seotland limestone.	
		Kalkberg limestone.	
		Coeymans limestone.	
	Cayugan,	Manlius limestone.	
		Rondout waterlime.	
		Cobleskill limestone.	
		Salina beds.	
Silurian,	Niagaran,	Guelph dolomite.	
		Loekport dolomite.	
		Clinton beds, including Rochester shale at top.	
	Oswegan,	Medina sandstone, including Oneida conglomerate.	
		Oswego sandstone.	

In Albany County, New York, southwest of the city of Albany, the Oriskany sandstone has a thickness of but one or two feet. Westward, in Schoharie County, the thickness increases somewhat. In the West Hill section, near Schoharie, it has a thickness of 6 feet 3 inches.[36] Here it consists of a dark siliceous and very fossiliferous limestone, apparently a mixture of quartz and lime sand

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36. New York State Museum Bulletin 92, 1906.

grains.   At this place it overlies the Port Ewen limestone and is in turn overlain by the Esopus shale.   Further west, in southern Herkimer County, it disappears entirely, but in Oneida County, in the vicinity of Oriskany Falls, the locality after which the formation was named, it is again represented by 20 feet of nearly pure quartz sandstone.   Westward, it thins again, until at Manlius, in Onondaga County, it has decreased to one foot, five miles further west it again increases to 3 feet 6 inches.   Four miles beyond this point it thins to 1 foot 6 inches and one and one-half miles further decreases to 6 inches and finally disappears entirely.   In this region the formation is represented by a very light gray, occasionally pinkish, granular quartzite.   In some of the localities the sand grains are well cemented and the rock durable, while at others it is friable and weathers to a rusty brown.   It rests upon 40 feet of limestone which belongs to the New Scotland and Coeymans formations, the Becraft and Port Ewen limestones being here absent.[37]   Overlying it is the Ononadaga limestone.   The sandstone appears again at Split Rock, southwest of Syracuse, and thickens going westward until at Skaneateles Falls it is 18 feet thick.   Beyond it thins rapidly until six miles westward it is down to 10 inches.   From this point westward, with two exceptions, there are no more large lenses observable, the formation being represented by a thin sheet of sandstone, seldom more than a few inches in thickness.   In the Buffalo region the formation disappears as a continuous sheet and is represented only by masses of dark shale and a conglomerate composed principally of small water worn fragments of water lime in a matrix of indurated clay, present in well defined erosion channels and irregular depressions in the top of the underlying water lime of the Cobleskill formation.   All of the Devonian formations of eastern New York below the Oriskany, together with that portion of the upper Silurian above the Cobleskill, are absent in this region.[38]

Beyond the Niagara river in Ontario the Oriskany reappears irregularly over a very limited area and finally disappears.   Where it · is present the thickness ranges from 6 to 25 feet.[39]   It varies somewhat in composition.   In some places it consists of a white, compact quartzite, while in others it is made up of coarse grains of quartz, some of them being an eighth of an inch in diameter, and pretty well rounded.   Occasional grains of feldspar are also present.   Sometimes the rock is slightly calcarous.   Fossils are abundant.[40]

South of Albany, New York, at Becraft Mountain, on the east side of the Hudson river, near Hudson, the Oriskany is represented by a

37. New York State Museum Bulletin 82, 1905.
38. New York State Museum Bulletin 99, 1906.
39. Bulletin Geological Society of America, Vol. 11, pp. 241-332, 1900.
40   Canadian Geological Survey, Report of progress from its commencement to 1863. pp. 359-389.

L‍⌐⌐L⌐⌐L⌐⌐⌐L⌐⌐⌐L 1 millimeter
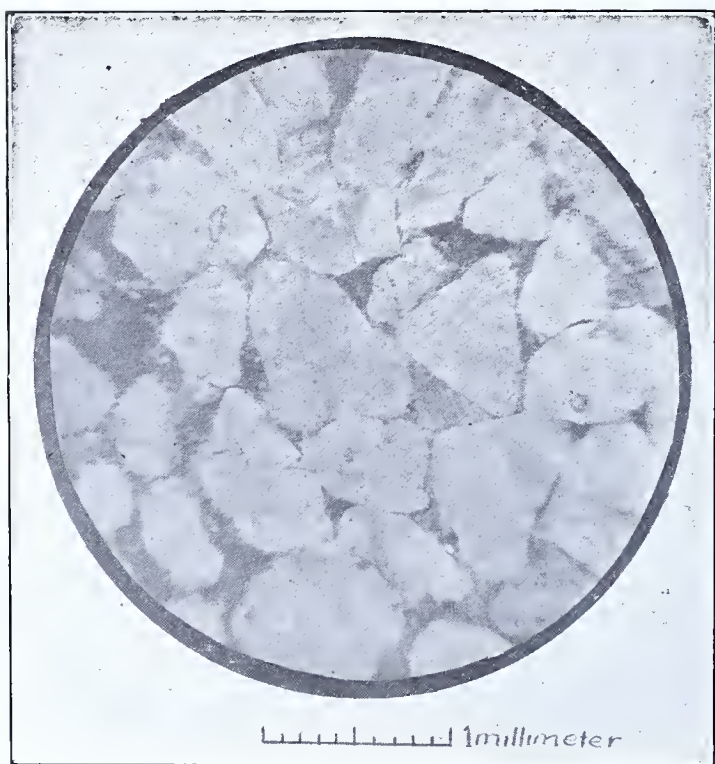
PLATE LIII.

Micrograph of a thin section of calcareous Oriskany
sandstone from Kingston, New York.

stratum 1 to 2 feet thick, varying in composition from a siliceous lime-stone to a quartzite rich in fossils. It is underlain by the Port Ewen limestone and overlain by the Esopus and Schoharie grits. Still further south, in the vicinity of Kingston, in Ulster County, the thickness increases, being 5 to 60 feet in this region. The formation here consists of a quartz conglomerate and sandstone or quartzites, calcareous quartz and rock and siliceous lime sand rock. It is likewise underlain by the Port Ewen limestone and covered by the Esopus and Schoharie grits.[41]

A typical specimen of the calcareous quartz sandstone from the Oriskany formation, collected by the writer in the vicinity of Kingston, has a light gray color, and consists of quartz grains cemented by calcite. Under the microscope, in this section, many of the grains are seen to be pretty well rounded, the majority of them having at least had their corners rounded off. Dust like particles, too fine to be determined, but probably in part consisting of fluid or gaseous inclusions occur in most of the grains. These often occur along definite lines which under the high power of the microscope are seen to be incipient fractures. Hair like inclusions of rutile are present in some of the quartz grains. Under the cross-nicols most of the grains prove to be portions of individual crystals of quartz, but a few are seen to be made up of an aggregate of still smaller grains. Many of the grains show strain shadows or undulatory extinction under the cross nicols. The space between the grains is occupied by calcite. Plate LIII shows the appearance of a thin section of this rock under the microscope. Another thin section of a more calcareous specimen was also examined. In this case the calcite is in excess of the quartz grains. The latter show very ragged outlines. Apparently the quartz has been attacked on the margins and replaced in part by calcite. Almost all of the grains show undulatory extinction. Inclusions are not abundant.

To the southwest of Kingston, in southeastern New York and adjacent portions of New Jersey, the Oriskany becomes involved in the Appalachian folding, which is described in a later paragraph under its geologic history. Isolated outcrops occur along a belt starting north of Greenwood Lake and extending south beyond Newfoundland, while the main belt of the formation continues south, from near Kingston, through New Jersey into Pennsylvania. Along the west shore of the southern end of Greenwood Lake the formation consists of a white, light gray, or buff colored quartzite, containing much coarse sand and a considerable number of quartz pebbles. It has a thickness of about 28 feet. In the Newfoundland region the thickness is about

41. New York State Museum Bulletin 92, 1906.

50 feet. Some portions of the quartzite at this place are calcareous and weather to a loose grit. These portions are usually fossiliferous.[42] Along the upper Delaware valley the strata referred to the Oriskany have a thickness of 170 feet. They are for the most part siliceous limestones, but the summit of the formation along the southern half of Wallpack Ridge becomes a sandstone. These beds rest upon 80 feet of shale which have been referred to the Port Ewen of New York, on account of their position. Overlying the Oriskany are 375 feet of grit correlated with the Esopus of New York. A limestone, probably the Onondaga, rests upon this grit.[43]

The Oriskany enters Pennsylvania in southeastern Monroe county, as a single outcrop, in the form of a narrow belt dipping towards the northwest. It continues southwest along this belt through southeastern Carbon and Schuylkill counties. From that point on, however, there are a large number of nearly parallel outcrops, running in a general southwesterly direction and occupying a belt approximately 56 miles wide, in Perry, Juniata, Mifflin, Huntingdon and Centre counties. This is the area in which folding occurred at the close of the Paleozoic Era, so that the Oriskany has been brought to the surface many times on the flanks of the eroded anticlines.

Along Broadhead Creek, near the Delaware Water Gap, the Oriskany formation consists, from the top down, of 5 feet of pebbly, massive, calcareous sandstone, 38 feet of cherty, fossiliferous, calcareous shale, and 1 foot of quartz conglomerate. It is underlain by a fossiliferous, argillaceous limestone and overlain by a shale.[44] South, in the vicinity of Bossardsville, in Monroe county, the formation consists of a grayish-white, rather coarse grained sandstone, with many small flat pebbles, which have a darker appearance than the enclosing matrix. It is usually much disintegrated and has been used in the mnufacture of bottle glass. No exact measurements are possible here, but it is estimated the sandstone has a thickness of 150 to 200 feet.[45]

Continuing southward, in the vicinity of the Lehigh Gap, the Oriskany formation consists of sandstone and conglomerates of resistant character that are responsible for Stony Ridge. The formation is divisible into two portions. The upper member is composed of a coarse sandstone or conglomerate, varying in thickness from 150 to 175 feet. The cementing material is mainly calcareous and its removal in many cases causes the rock to disintegrate. Numerous sand quarries are, therefore, located along the ridge. The sand grains are usually well rounded and the stone has a white to light

42. Bulletin, Geological Society of America, Vol. 5, pp. 367-394. 1894.
43. Journal of Geology, Vol. 17, pp. 351-379. 1909.
44. Second Geological Survey of Pennsylvania. Final Summary Report, Vol. 2, pp. 1034-1141. 1892.
45. Second Geological Survey of Pennsylvania, Report G. 6, pp. 283-284. 1881.

yellow color. The lower member of the formation consists of quartzitic shales, which are very fossiliferous. Those shales vary in thickness from 200 to 300 feet.[46]

In Perry county the formation nowhere exceeds 20 to 25 feet in thickness. It varies from white, through yellow to red in color, and in hardness from loose sand to a flinty rock. In some places it is a fine conglomerate made up of a mass of small, white quartz pebbles, while in other places it is a sandstone. In the vicinity of New Bloomfield, central Perry county, the grains are more or less rounded.[47] According to Grabau the Oriskany of Perry county overlies 90 feet of flinty shale, the upper portion of which contains New Scotland fossils.[48]

To the west of this area in Mifflin and Huntingdon counties the Oriskany sandstone reaches its maximum development. Northwest of Lewistown, according to Dewees[49], the Oriskany sandstone has a thickness of 110 feet and is overlain and underlain by shale. Remnants of it are here preserved in three synclinal flexures. While in most cases it is considerably stained by limonite, there are several places where it has weathered to a practically white, pure quartz sand. The formation as exposed in the vicinity of Lewistown is very fossiliferous, especially in its upper portion. At McVeytown, about 12 miles southwest of Lewistown, it reaches a thickness of 140 feet. Here under favorable conditions it has also in places disintegrated to a white quartz sand through weathering. Twelve miles further to the southwest, at Mount Union, along the same belt of outcrops as those occurring at Lewistown and McVeytown, it has decreased in thickness to 95 feet. The exposures in this vicinity are poor, but boulders marking the outcrop indicate that the formation consists of a fairly pure quartz sandstone.

Four miles west of Mount Union, on the opposite limb of the Jacks Mountain anticline, in the vicinity of Mapleton, the Oriskany again reaches a thickness varying from 125 to 212 feet. Here it also consists of a practically pure quartz sandstone or quartzite, with occasional thin fossilferous conglomeratic layers containing quartz pebbles up to three eighths of an inch in diameter. Continuing westward, just beyond the town of Huntingdon, the Oriskany occurs in the eastward dipping flank of the syncline of which the outcrop through Mapleton forms the eastern limb. Here along Warriors Ridge, in the vicinity of McConnellstown, it has a thickness of only 60 feet. It is still a fairly pure quartz sandstone but contains more oxides of iron. Still further to the westward, at Altoona, the Oriskany horizon appears at the surface for the last time, dipping westward un-

46. Top. and Geol. Surv. Penna. Report No. 4, pp. 52-55.
47. Second Geol. Surv. of Penna. Report F2.
48. New York State Museum, Bull. 92. 1916.
49. Second Geol. Surv. of Penna., Report F. p. 49.

derneath the later Paleozoic strata which underlie the Appalachian plateau. In this region it has a thickness of only 20 feet and consists of a thick bedded, generally coarse grained, gray or buff colored sandstone.[50] It is overlain by the Marcellus black shale, the Onondaga apparently being absent.

Southward from its area of maximum development in Mifflin and Huntingdon counties, the Oriskany outcrops continue in Bedford and Fulton counties wherever this horizon of the Devonian has been brought to the surface by the erosion of the anticlinal folds, but it rarely exceeds a thickness of 90 feet.[51] It is still a sandstone but in places considerable calcareous material is present, thus strongly contrasting it with the Juniata valley section just described, where in no case in the numerous thin sections of the rock examined by the writer under the microscope was any calcite noticed.

The Oriskany of Maryland has been studied in detail and described at considerable length in a recent monograph on the Lower Devonian published by the Maryland Geological Survey. The outcrops form a continuation of the belt which occupies the Appalachian mountain region of central Pennsylvania and extend across Maryland into West Virginia. In Maryland the Oriskany consists in its lower portion of a black cherty shale, which has been called the Shriver Chert member and in its upper part of a calcareous sandstone or arenaceous limestone, to which the term Ridgeley sandstone has been applied. The Shriver Chert member consists of a dark silicious shale, containing large quantities of black, impure chert in the form of layers or nodules. In the most easterly of the Oriskany outcrops in Maryland it is absent, while in those farthest to the west it reaches a total thickness of 100 feet. The Ridgeley sandstone member is composed of a calcareous sandstone which passes in places into an arenaceous limestone because of the great development of calcareous cement. It also contains conglomeratic beds, one of which in the vicinity of Cumberland contains pebbles resembling grains of wheat. Upon weathering, the calcareous cement is dissolved out by the surface waters and the rock disintegrates, forming sand and large boulders of sandstone. The character of the rock undergoes a change towards the eastward, becoming more calcareous, until in the North Mountain area it is a limestone sufficiently pure to be used as a source of lime. Here it contains numerous beds of chert. In thickness the Ridgeley member varies from 250 feet in the western exposure to 50 feet or less at the North Mountain outcrop. The boundary between the two members of the Oriskany is not sharp. The amount of chert diminishes in the upper part of the Shriver member and thin beds of sandstone appear, forming transition beds

50. Journal of Geology, Vol. 14, 1906, pp. 618-630.
51. Second Geol. Surv. of Penna. Report T2.

into the overlying sandstone. In Maryland the Oriskany in most places comes to rest upon the New Scotland, the Becraft appearing only in Washington county, where it consists of an arenaceous limestone with much interbedded chert, having a thickness of about 85 feet. At the top of the Oriskany there is evidence for at least a short erosional unconformity, followed by the deposition of the Romney shale, which in its lower part contains a fauna of Onondaga age.

South of Maryland, in West Virginia, especially in the area covered by the Pawpaw-Hancock folio of the United States Geological Survey, the Oriskany formation is again developed to an extent comparable to the deposits of central Pennsylvania, except that often considerable quantities of calcareous material are present in it. In general it is a pure white to gray calcareous sandstone with minor amounts of quartz conglomerate. Calcareous material predominates in places, especially in the eastern areas, and forms a limestone sufficiently pure to be burned for field lime. Further west in the area along Tonoloway and Warm Spring Ridges, the sandstone is entirely free from lime at the surface and is quarried for glass sand. A fine quartz pebble conglomerate is usually present at or near the top, whose pebbles range up to a quarter of an inch in diameter. Along Warm Spring Ridge the formation has a total thickness of about 150 feet, while on Tonoloway Ridge it reaches a thickness of 417 feet. The Oriskany of this area is very fossiliferous. In the sandstone the fossils are present only as interior casts, as in the case of the Pennsylvania occurrances, while in the calcareous portions of the formation, in the eastern area, the entire shells are usually present. The fossils are all characteristic of the upper Oriskany of New York and as the formation comes to rest on limestone of Becraft and New Scotland age (with the exception of one occurance exposed in the Western Maryland railroad cut opposite Great Cacapon, in the western part of the area) an erosion unconformity evidently exists, here represented by the absence of the lower Oriskany. In this area the Oriskany is also overlain by the Romney shale, the lower member of which contains fossils of Onondaga age. There is evidence of a minor erosion unconformity between this member and the sandstone, represented by the irregular surface of the latter at the contact and by the sudden transition from sandstone into shale. A conglomerate also occurs locally at the base of the Romney.

To the southwestward, in Virginia, the Oriskany has been described by N. H. Darton in the vicinity of Stanton, as consisting of from 150 to 300 feet of buff colored, fine grained, massive sandstone, containing an abundance of casts and impressions of fossils.[52] The forma-

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52. U. S. Geol. Surv. Folio 14.

tion at this place has been called the Monterey sandstone. To the southeastward it thins rapidly and in places is entirely absent, due to an erosional unconformity.

In northeastern Alabama and northwestern Georgia the Oriskany formation is represented by what is locally called the Frog Mountain sandstone. In the vicinity of Rome, Georgia, it is a formation of chert and sandstone, carrying fossils of Oriskany age. The sandstone is either a white, quartzitic variety, or a yellow, porous one, with some feldspar. It rests with an erosional unconformity upon the Rockwood formation of the middle Silurian and is overlain by a black shale, known as the Chattanooga shale, also of Devonian age. In the Birmingham, Alabama, region it is rather coarse quartz sandstone or quartzite, ranging in thickness from 4 to 20 feet, also resting upon the Clinton of Rockwood formation of the middle Devonian and overlain by the Chattanooga shale.

In going westward from central Pennsylvania attention has already been called to the fact that the Oriskany formation passes under beds of later age. This horizon of the Devonian does not again come to the surface until central Ohio is reached, where Devonian strata have been exposed by the erosion of the Cincinnati dome. Here, however, the Oriskany has disappeared along with all of the strata representing the lower Devonian of the Appalachian Mountain region, so that the Onondaga limestone (locally called the Columbus limestone in Ohio) comes to rest upon the Monroe formation of the Upper Silurian, indicating an erosional unconformity during lower Devonian time, during which this part of Ohio was dry land. To the southwestward, in north central Kentucky, this unconformity represents a still greater interval of time, as here the Onondaga (Jeffersonville) limestone comes to rest upon the Louisville limestone of the Middle Silurian.

Geologic History of the Oriskany Formation.

From the preceding description of the Oriskany formation it is seen that it consists for the most part of a quartz sandstone or quartzite, which in part of the area over which it is distributed is exceedingly pure, so that where it has been sufficiently weathered it can be used as a source of glass sand. Occasionally thin beds of fine conglomerate are found in it, while at other times it is either argillaceous or calcareous. The fact that marine fossils are found in it indicate that it was deposited upon the sea floor, but in as much as it is a comparatively coarse sediment over most of the area where it is found, it shows that the shore line could not have been very far away from the place where it was laid down. It represents a near shore, shallow water deposit, laid down in a narrow arm of the
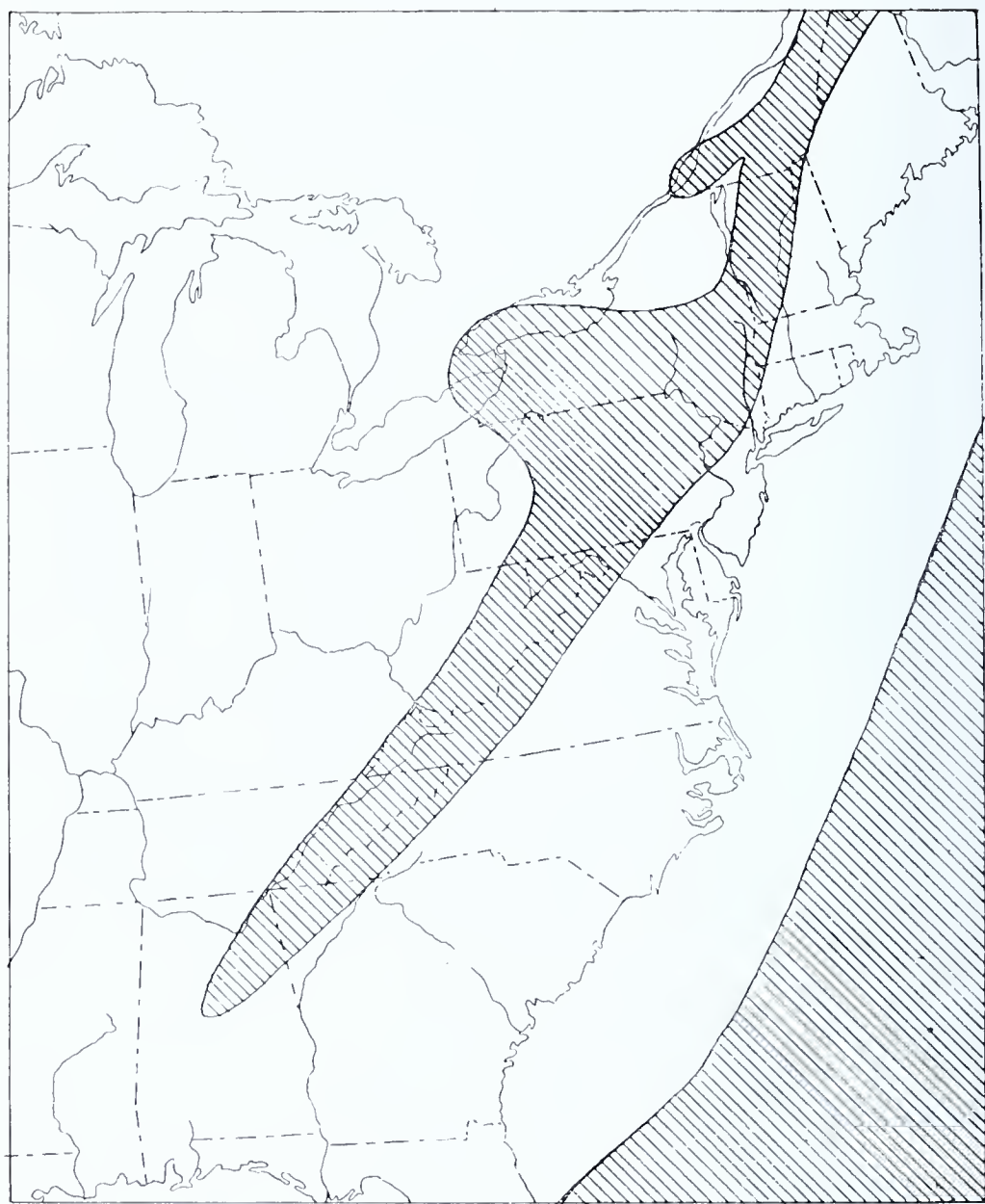
PLATE LIV.

Paleogeography of the Eastern United States during Oriskany time.

sea which occupied the present Appalachian Mountain region during Devonian time.

Plate LIV shows the probable maximum extent of this interior sea as indicated by the present distribution of the Oriskany sediments over the eastern United States. A connection with the Atlantic Ocean is shown by the way of the St. Lawrence valley region. The map shows a land area along the present Atlantic border of the United States, extending out some distance into the Atlantic from the present shore line. The evidence for the existence of this land area is furnished by the coarse nature of much of the Oriskany sediments found in the Appalachian region. Such sediments could only be deposited near shore. A study of the formations exposed to erosion around the shores of this interior sea during Devonian time indicates that along its western margin, (with the possible exception of a small area in northern Ohio, where the Sylvania sandstone of the Upper Silurian, which has a thickness of about 20 feet feet may have been exposed to erosion), no other formations except shales and limestones were furnishing sediments. This leaves only the land area to the east and to the north as a possible source for the extensive sandstone deposits of Oriskany age in central Pennsylvania and northeastern West Virginia. It is not likely that much material was washed as far south as central Pennsylvania and northern West Virgina from northern New York State, so that undoubtedly the source of the sands was a land area exposed to erosion to the east, from which streams flowed in a westerly direction into the Oriskany sea, washing sands down with them. Below the Oriskany sandstone of Pennsylvania are found, besides limestones and shales, the Tuscarora sandstone, which is a very pure quartz sandstone; the Juniata formation, made up in great part of sandstone, and a considerable thickness of Cambrian sandstones, of the lower Paleozoic, which rest upon pre-Cambrian gneisses and schists, which also contain abundant quartz grains. It is highly probable that parts of all of these formations were exposed to erosion during Oriskany time over portions of the eastern land area, as all occur outcropping over areas farther east than any of the known Oriskany outcrops. These formations, therefore, must be considered as the source of the present Oriskany sandstone.

The question arises as to how the quartz grains, in places, were so completely separated from the minerals which accompanied them in the original rocks as to give rise to sand deposits which analyze over 99% silica, as is the case in central Pennsylvania and northeastern West Virginia. The methods by which nature accomplishes this have already been discussed in a previous chapter, dealing with the raw materials used in the manufacture of glass, so that it is only

necessary here to state briefly the conditions which must have pre-vailed over this area during Oriskany time and the interval just prior to it, which resulted in this type of deposit.

The lower Devonian formations, just below the Oriskany, are present only in a small portion of the area occupied by the Oriskany formation itself, namely eastern New York, central Pennsylvania, western Maryland, and northeastern West Virginia. Passing southward from this area the Oriskany comes to rest upon lower and lower formations until in northern Alabama it lies upon the Clinton formation of the Middle Silurian. The same thing holds true in going westward from central New York, where in the vicinity of Buffalo only a few thin patches of the uppermost Oriskany are found on top of the Cobleskill limestone of the Upper Silurian. This shows that during this part of the Devonian the seas were much more restricted. Also during this interval only limestones and shales were deposited over the areas of deposition, which shows that the land to the east was low lying and, therefore, not undergoing the rapid erosion necessary to furnish coarser sediments.

When land areas are low, chemical decomposition is the predominating process of weathering, rather than mere mechanical disintegration of the rocks. As has already been pointed out, in the previous chapter referred to, such a thorough decomposition is necessary as the first stage in the formation of a pure quartz sandstone, in order that all the silicate minerals accompanying the quartz in the rocks will be thoroughly altered and disintegrated into soft, readily pulverized secondary products, leaving the quartz grains free. Then it is only necessary to have these grains separated from this thick mantle of residual soil by some sorting and transporting agent, such as a running water or the wind.

In the case of the Oriskany sandstone some of the formations from which it was derived were already fairly pure quartz sandstone, running as high as 97% in silica, such as the Tuscarora sandstone, for example. This formation reaches a considerable thickness wherever the Oriskany sandstone is well developed, so that much of the sand of the latter may have come from parts of this formation, exposed to erosion along its eastern outcrops during Oriskany time.

Running water, in the form of sreams, apparently was the principal transporting agent which carried the Oriskany sands from the eastern land area into the shallow Appalachian sea. At the beginning of Oriskany time this land was elevated slightly, so that coarse material was washed down by the streams. This is indicated by the fact that where, during the lower Devonian, only limestones and shales had been accumulating, sands were deposited at this stage. The thickest beds of sand were laid down at the mouths of the larger

streams in the form of large deltas, while the fine material was carried farther out into the sea, where it finally settled out around the margins of the deltas. Wave action and shore currents undoubtedly also played a part in the separation of the coarse material from the fine. In the area beyond, and between the deltas, in places a little limestone also accumulated.

Wind action may also have played a part in the separation of the quartz grains from other accompanying minerals, although the evidence for this is not at all conclusive. None of the Oriskany sandstones examined by the writer under the microscope showed as perfectly rounded grains as are often found in wind blown sands. In the description of a section of calcareous sandstone from Kingston, New York, attention has already been called to the fact that many of the grains show imperfect rounding. In numerous sections of Oriskany sandstone from central Pennsylvania examined under the microscope, they were seen to be made up of an interlocking mosaic of angular quartz grains. This angular shape, however, may in part be due to secondary changes which have occurred in the rock since it was deposited. Silica is the bond of these sandstones and it has crystallized around the original grains of sand in such a manner that the new molecules of silica have taken on the same crystallographic orientation as those of the grains about which they formed, so that under the microscope the two appear to be continuous. It is only occasionally that the original shape of the grain can be determined from the distribution of inclusions in it. Rounded grains can at times be detected in this manner in the Oriskany sandstone of Pennsylvania. As has already been stated the Appalachian sea was much more restricted during the early part of the Devonian, just prior to the deposition of the Oriskany. It is possible that sands were washed out onto the low lying plain, which was later occupied in part by the Oriskany sea. Winds may have shifted these sands about and separated much of the finer material from them in a manner already described. Then when the sea encroached upon this territory the waves reworked it and marine fossils became imbedded in it. Also with the elevation of that part of the plain to the east streams picked up the sand again and carried it westward to deposit it on their deltas. In some of the Oriskany sandstones of central Pennsylvania distinct cross bedding of the stream or fluviatile type may be recognized.

After the Oriskany sediments had been deposited conditions favorable either for marine or continental sedimentation, with only occasional periods of erosion, continued to exist throughout the Appalachian area until the end of the Paleozoic. At the close of this era a great crustal disturbance set in over the region occupied by the Appalachian trough, which had been gradually subsiding through-

out the Paleozoic. The thick series of horizontal strata which had accumulated were now subjected to enormous lateral pressure brought about by the gradual shrinkage of the earth, which caused them to become folded into a series of anticlines and synclines, following a northeast and southwest trend. At the same time they were elevated high above sea level.

During this period of folding the Oriskany sands of central Pennsylvania were converted into hard quartzite, in part by recrystalization of the quartz grains and in part by the deposit of secondary silica around them.

The region has not been submerged below sea level again since this disturbance, but has been exposed to erosion continuously from that time to the present. Several periods of vertical elevation have occurred, which from time to time have re-elevated the area after it had been worn down almost to sea level by erosion. The first one of these uplifts occurred towards the close of the Cretaceous. By that time the Appalachian area had been worn down to a nearly level plain, standing only very slightly above sea level. Much of the Paleozoic strata, especially along the arches or anticlines of the folds, had been removed by erosion so that the lower Paleozoic strata had been brought to the surface in places. After this uplift erosion again became active and broad valleys were formed along the softer strata, exposed to erosion, leaving only the more resistant ones, standing out as long, nearly parallel ridges, the tops of which still approximately approached the level of the old elevated Cretaceous peneplain. This period of erosion was again interrupted by an uplift which occurred during early Tertiary time, causing the streams to again commence to incise their channels in the broad valleys developed during the previous cycle of erosion. Since then there has probably been at least one other such movement, at the close of the Tertiary period. The tops of the higher ridges of central Pennsylvania, therefore, mark the level of the old erosion plain developed prior to the close of the Cretaceous. This accounts for the fact that they all have approximately the same level, thus furnishing an even sky line when viewed from the top of any one of them. The broad, nearly level areas which are usually more or less dissected by stream valleys between these ridges of resistant rock, represent areas underlain by softer and more readily eroded formations. These areas were developed during the second cycle of erosion, after the Cretaceous peneplain had been elevated. The valleys which are cut in them were formed after this second cycle was brought to a close by another uplift.

PLATE LV.

Fig. 1. Photomicrograph of a thin section of bluish grey quartzite from North Quarry to Westbrook Glass Sand Co., Mill Creek, Huntingdon County, Penna. Crossed Nicols.
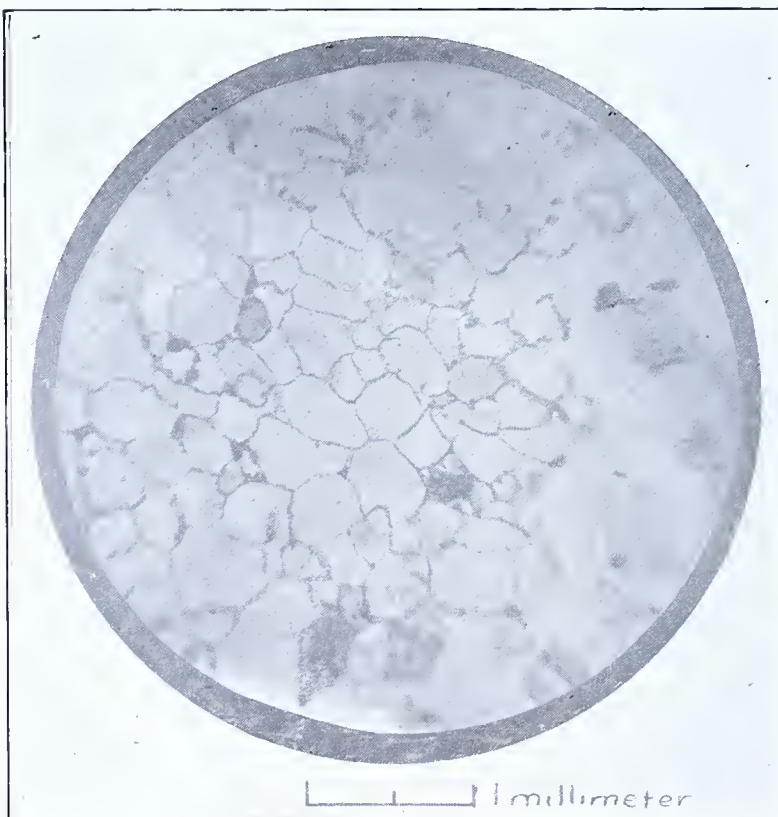
Fig. 2. Photomicrograph of a thin section of sandstone stained by limonite. Juniata White Sand Company's Quarry, Mapleton, Penna.

CHAPTER XV.

ORISKANY GLASS SAND DEPOSITS.

Those portions of the Oriskany formation suitable for glass sand occur in two main areas, one in central Pennsylvania, confined mainly to Huntingdon and Mifflin counties, and the other in northeastern West Virginia, in Morgan county. These portions of the formation owe their value as glass sand deposits to two causes. First, they were laid down under conditions which resulted in an almost complete separation of the quartz grains from other minerals, so that a very pure quartz sand resulted, which later on became consolidated into a sandstone or quartzite, and, secondly, these portions of the formation were later exposed to weathering under conditions which have resulted in the partial, or in places complete disintegration of the rock to friable sandstone or loose sand, without the infiltration of any iron bearing solutions. Wherever these two conditions have prevailed, and the formation has a sufficient thickness, it is suitable for glass sand.

Characteristics Due to Conditions of Original Deposition.

Attention has been called to the fact that only these portions of the Oriskany formation are suitable for glass sand in which considerable weathering has occurred, so that the sandstone has been disintegrated sufficiently to become friable. A number of thin sections of the least altered portions of the formation in the vicinity of glass sand deposits were therefore examined by the writer to determine what the rock was originally like, before it had undergone any disintegration. An excellent exposure of only very slightly weathered Oriskany sandstone is in the abandoned quarry of the Westbrook Glass Sand Company, a short distance northeast of Mill Creek, in Huntingdon county. It consists of a hard, bluish grey, vitreous quartzite, which in thin section under the microscope, with crossed nicols, is seen to be made up of an interlocking mosaic of angular quartz grains. An occasional grain of altered feldspar is present and minute quantities of iron oxide occur along a few of the irregular incipient cracks developed between some of the grains of quartz. Dust like inclusions, too fine to be determined, are abundant in many of the grains. Occasionally a piece of quartz contains abundant rutile needles and now and then one with a few small prismatic crystals of apatite may be observed. Much of the quartz shows strain shadows, revealed by undulatory extinction when viewed between crossed nicols. From the distribution of the minute inclusions

in a few of the grains it can be seen that originally some of them had a rounded outline, which has been obliterated by the crystallization of additional silica around them, whose molecular orientation is similar to that of the original grain, so that the two behave as an unit when viewed between crossed nicols under the microscope. The secondary silica, however, is free from inclusions. The deposition of this silica has resulted in the filling of all the original pore space of the rock and forms the interlocking mosaic of quartz grains now seen under the microscope. Figure 1, Plate LV, shows a photograph of this sandstone as it appears in this section between crossed nicols under the microscope. As seen from the above description the rock consists practically entirely of quartz grains, the small quantities of other constituents present being negligible. A chemical analysis of this rock shows it has the following composition:

SiO_2,	99.39%
Al_2O_3,	.30%
Fe_2O_3,	.12%
MgO,	none
CaO,	.29%
H_2O,	.17%
TiO_2,	.03%
	100.30%

Another sample taken from a ledge of the harder rock left in the northeast corner of the north quarry of the Pittsburgh White Sand Company, south of Mapleton, Huntingdon county, consists of a white sandstone, grains of which can only be removed with difficulty with the fingers. Here and there through it are small specks of limonite. When examined in thin section under the microscope it shows a very much similar composition and texture to the specimen from the Westbrook quarry. A few grains were also present in it which, from the distribution of their inclusions, appear at one time to have been rounded. One well rounded grain of hornblende was noticed. Undoubtedly the alteration of this mineral, which is silicate containing some iron, accounts for the scattered specks of limonite. Another very much similar specimen from the Juniata White Sand Company's quarry, south of the above locality, which was also speckled here and there with limonite, likewise showed a well rounded grain of hornblende in a thin section examined. The following screen analysis shows the size of the grains of sandstone encountered in the North quarry of the Pittsburgh White Sand Company:

Screen Analysis of Sand from North Quarry of Pittsburgh White Sand Company.

Remaining on 6 mesh _____(.131 inch diameter),   .42%
Through   6, remaining on   8 mesh (.093 inch diameter),   .42%
Through   8, remaining on 10 mesh (.065 inch diameter),   1.73%
Through 10, remaining on 14 mesh (.046 inch diameter),   1.57%
Through 14, remaining on 20 mesh (.0328 inch diameter),   2.42%
Through 20, remaining on 28 mesh (.0232 inch diameter),   7.36%
Through 28, remaining on 35 mesh (.0164 inch diameter), 18.90%
Through 35, remaining on 48 mesh (.0116 inch diameter), 47.84%
Through 48, remaining on 65 mesh (.0082 inch diameter), 14.71%
Through 65, remaining on 100 mesh (.0058 inch diameter),   2.18%
Through 100, remaining on 150 mesh (.0041 inch diameter),   .48%
Through 150, remaining on 200 mesh (.0029 inch diameter),   .37%
Through 200, _____   .42%
                                                          99.13%

A specimen of only partially weathered Oriskany sandstone taken from an outcrop on the southeast dipping limb of a narrow syncline, on whose northwest dipping portion the Granville mine of the Pennsylvania Glass Sand Company, southwest of Lewistown, Mifflin county, is located, consists of a hard white sandstone, stained with a little limonite along a few minute crevices.   Under the microscope, in thin section, it is also seen to be made up of a mosaic of interlocking quartz grains, some of which between crossed nicols show undulatory extinction.   Dust like inclusions are also abundant in many of the grains, and from these it can be seen that some of the grains were originally rounded.   The size of the grains of the Oriskany sandstone in this vicinity is indicated by the following screen analysis, made from a sample taken from the Granville mine.

Screen Analysis of Sand from Sample of Oriskany Sandstone from the Granville Mine.

Remaining on 14 mesh, _____(.046 inch diameter),   .01%
Through 14, remaining on 20 mesh (.0328 inch diameter),   .28%
Through 20, remaining on 28 mesh (.0232 inch diameter),   1.31%
Through 28, remaining on 35 mesh (.0164 inch diameter),   5.15%
Through 35, remaining on 48 mesh (.0116 inch diameter), 20.77%
Through 48, remaining on 65 mesh (.0082 inch diameter), 36.80%
Through 65, remaining on 100 mesh (.0058 inch diameter), 24.32%
Through 100, remaining on 150 mesh (.0041 inch diameter),   5.14%
Through 150, remaining on 200 mesh (.0029 inch diameter),   2.91%
Through 200, _____   2.28%
                                                          98.97%

The Oriskany sandstone of Warriors Ridge, where the Juniata river crosses it just above Huntingdon, is a light buff colored quartzite.   Under the microscope it is seen to also consist of an interlocking mosaic of quartz grains, some of which from the distribution of their inclusions appear originally to have been rounded.   Dust like inclusions are abundant in many of the grains.   An occasional grain with rutile needles or apatite is present.   A little limonite or other iron oxide occurs between some of the grains, which give the rock its buff color.   This rock has weathered to a loose sand in places on Warriors Ridge, southwest of the river.   A screen test of the sand gave the following results:

Screen Test of Sand from Warriors Ridge.

Remaining on 14 mesh, _____(.046 inch diameter),	.20%
Through 14, remaining on 20 mesh (.0328 inch diameter),	1.04%
Through 20, remaining on 28 mesh (.0232 inch diameter),	2.41%
Through 28, remaining on 35 mesh (.0164 inch diameter),	4.94%
Through 35, remaining on 48 mesh (.0116 inch diameter),	14.24%
Through 48, remaining on 65 mesh (.0082 inch diameter),	43.97%
Through 65, remaining on 100 mesh (.0058 inch diameter),	30.12%
Through 100, remaining on 150 mesh (.0041 inch diameter),	1.48%
Through 150, remaining on 200 mesh (.0029 inch diameter),	.50%
Through 200, _____	.78%
	99.68%

The sand has a light brown color, indicating that it contains too much limonite to yield a first class sand.

Another sample obtained along Warriors Ridge south of Huntingdon, between Entriken and Hummel station, also consists of a buff colored quartzite, which shows very much the same characteristics under the microscope as the specimen described above, except that a little more iron oxide was present between the quartz grains. More of the grains showed that they were originally rounded. Some of the grains showed undulatory extinction between crossed nicols. Occasional grains of hornblende are present, one of which showed a secondary growth of a lighter colored amphibole around the original grain, whose crystallographic orientation was similar to that of the latter. All of the sands derived from the weathering of the quartzite between this locality and Huntingdon contain too much limonite to yield the best quality of glass sands.

From the description of the above samples of Oriskany sandstone, from localities where these have yielded glass sand, it is seen that over the areas during the time they were deposited, conditions were such that nothing but quartz grains were laid down, as no other minerals occur in them, except now and then an occasional grain of hornblende or altered feldspar. Silica forms the bond between the grains. This siliceous cement has been deposited in crystalline continuity with the original quartz, as a new outgrowth of the grains, the new material extinguishing simultaneously with the grain about which it was deposited when viewed under the microscope between crossed nicols. The result is that a slice of the rock has the appearance of an irregular mosaic, between crossed nicols. This compacting and cementing of the Oriskany sands into quartzites, accompanied by the partial recrystallization of the quartz grains themselves along their points of contact, occurred after their deposition, probably during the time this formation was subject to the great lateral compression towards the close of the Paleozoic era, which brought about the folded structure of the Appalachian Mountains.

Characteristics Due to Secondary Changes.

After the Oriskany sandstone, together with the other Paleozoic formations of the Appalachian trough, had been compressed into a

PLATE LVI.

Working face of North Quarry of Westbrook Glass Sand Company, Mill Creek, Pa.

series of parallel anticlines and synclines running in a northeasterly-southwesterly direction, and elevated high above sea level, erosion set in. As has already been stated, sufficient time had elapsed by the close of the Cretaceous to allow the various destructive agents of nature to wear the whole region down to a nearly level plain, which stood only a short distance above sea level, and across which the major streams flowed in broad meandering courses in an easterly direction to the Atlantic. Through this erosion of the folded strata the Oriskany, which had been covered over the whole area by later Poleozoic sediments, was exposed at the surface in a series of nearly parallel narrow belts, which follow the trend of the folds. Toward the close of the Cretaceous the region was again elevated vertically above sea level. This time the uplift was not accompanied by any lateral compression. The stream again began to cut their valleys downward, the major streams keeping their old meandering courses in an easterly direction towards the ocean, while the minor ones adjusted themselves to the structure of the underlying rocks, by shifting their courses to the softer, more readily eroded formations. For this reason these streams in general flow either in a northeasterly or a southwesterly direction, as the outcrops of the various strata follow along this line, parallel to the axes of the folds. As has already been stated this cycle of erosion was again interrupted, after broad valleys had been developed in the softer strata, by a third vertical uplift, which occurred during early Tertiary time, and possibly by a fourth during the late Tertiary.

When the Oriskany is first brought near the surface, and before it has undergone any change, it consists of a well cemented, pure quartzite over those areas where the glass sand deposits occur. In order for it to become available for glass sand it has to undergo sufficient disintegration through weathering to be converted into a friable sandstone or loose sand. This has occurred only along comparatively small portions of its entire outcrop, where conditions were especially favorable.

During the period of folding, and possibly also during the later crustal disturbances which resulted only in vertical uplift, the Oriskany sandstone was fractured to a considerable extent, while the more plastic shales with which it occurs interbedded yielded by flowage to the stresses to which they were put. This shattered nature of the Oriskany is illustrated in Plate LVI, which shows the southwest working face in the North Quarry of the Pittsburgh White Sand Company, south of Mapleton. These fractures allow the surface waters to get access to the sandstone formation wherever it is exposed at the surface, and from them this water gradually penetrates the sandstone itself along the contacts between the individual grains. The water undoubtedly dissolves a little of the silica, so that the

sandstone gradually becomes friable and eventually crumbles into a loose sand. This process is well illustrated in the abandoned quarry of the Westbrook Glass Sand Company, northeast of Mill Creek, Huntingdon county. The strata at this place dip 60° to the northeast. The outcrop of the Oriskany on the northeast side is marked by a steep escarpment shown in Figure 1, Plate LVII, which is a cross section of the quarry taken at right angles to the strike. Figure 2, Plate LVII, is a reproduction of a photograph taken in the quarry looking northeast. At this place from 20 to 30 feet of that part of the sandstone nearest to the surface was disintegrated sufficiently to be utilized for crushing into glass sand. This portion is shown by the cross hatching in the section of Figure 1, Plate LVII, referred to above. Underneath, the formation was found to consist of a hard white to bluish gray vitrious quartzite. That the disintegration starts at the surface and out from the joint planes or fractures in the quartzite is clearly shown in this quarry.

The bluish gray quartzite occurs farthest away from the surface, and also at some distance from the most pronounced zones of fracturing, where surface waters have not yet had access to it. Often, where joints do traverse it, the bluish gray color has disappeared along the fracture and the rock has become white, gradually grading out into the bluish gray color away from the joint. Where it has been acted on still more by surface waters the white quartzite has become disintegrated into a friable white sandstone, and in some places even into a loose white quartz sand. All gradations between bluish gray quartzite and white quartz sand are present in this quarry, the relative amounts of loose sand and friable sandstone being greatest nearest the surface where the leaching by surface waters has reached farthest into the sandstone from the joint planes.

The following analysis gives the chemical composition of the bluish gray quartzite and the loose white quartz sand derived from it by weathering:

Analyses of Quartzite and of Derived Sand. Westbrook Quarry, Huntingdon County.

	Bluish gray quartzite.	Sand derived from quartzite by weathering.
SiO_2,	99.39	98.75
Al_2O_3,	.30	.52
Fe_2O_3,	.12	.03
MgO,	none	none
CaO,	.29	.28
H_2O,	.17	.17
TiO_2,	.03	.03
Total,	100.30	99.78

PLATE LVII.

Looking northeast in North Quarry
of Westbrook Glass Sand Co.,
Mill Creek, Penna.

PLATE LVIII.
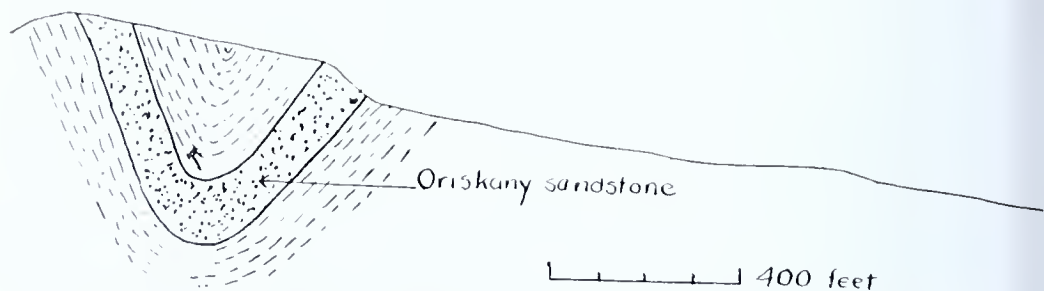
Fig. 1. Cross section of syncline at Granville mine of Pennsylvania Glass
Sand Co., southwest of Lewistown, showing position of Oriskany
outcrop.
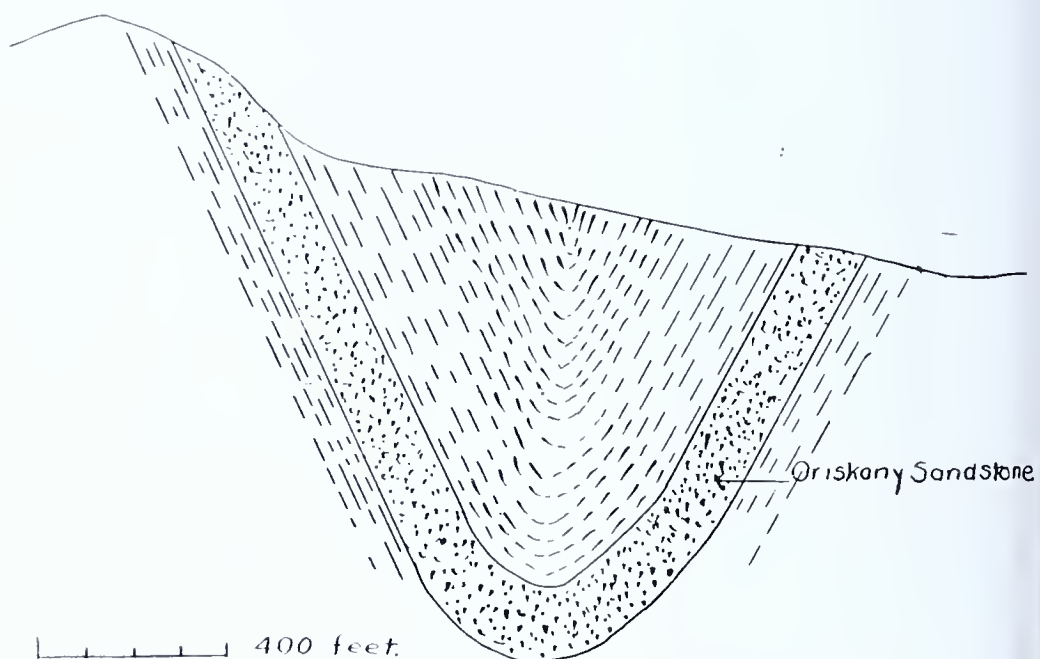
Fig. 2. Cross section of syncline of old Macklin mine at McVeytown showing
position of Oriskany outcrop.

The analysis of the quartzite emphasizes the fact that no bond except silica is present between the grains.

The change from bluish gray quartzite to friable white sandstone and loose sand seems to involve the solution of minute amounts of silica along the contacts between the individual grains of the rock, which gradually allows the water to work its way further and further into the quartzite and thus continue the disintegrating process. Quartz is ordinarily regarded as a mineral practically insoluble in water, but there seems to be considerable evidence that under certain conditions it does go into solution in small amounts. C. W. Hayes, M. L. Fuller, and C. H. Smyth cites examples where pebbles and grains of quartz in conglomerates have been attacked and etched by atmospheric waters, not only at the surface but also along bedding planes in the interior portions of the rock.[53] Hayes and Fuller attribute this solvent action of the water to the presence of organic acids in it derived from decomposing vegetable matter. Smyth has observed this same action of atmospheric water on quartz pebbles under certain conditions, but has not been able to satisfactorily explain just what substance present in the water produced the effect. In the case of the weathering of the quartzite in the Westbrook quarry, just described, the evidence also seems to indicate that such a solvent action has occurred along the contacts between the quartz grains, and that this has reduced the quartzite to a friable sandstone, or even to a loose sand in places. Thin sections of the rock in question, when examined under the microscope, as well as chemical analyses, show that the only bond present is silica.

It is a very difficult matter sometimes to explain just why the quartzite has become disintegrated sufficiently to be available for glass sand in one place while at another locality it appears as a hard vitreous quartzite practically at the surface. Several factors probably determine this. One of these is the relative position of the outcrop with respect to the topographic features of the land, and another is the amount of fracturing which the rock has undergone. In central Pennsylvania the Oriskany sandstone occurs interbedded between two layers of shale, which are comparatively impervious to the circulation of ground water. From observation made over this area upon a large number of outcrops of the formation it was found that as a rule disintegration was always most thorough where these were situated on the sides of the hills, so that the drainage down their slope would have to cross the sandstone outcrop, in other words an abundant supply of water to the outcrop appears to be a necessary requisite in producing thorough disintegration. Figure 1, Plate

53. Bull. Geological Society of America, vol. VIII, 1896, pp. 213-220; Jour. of Geology, Vol. X, 1902, pp. 815-821; Am. Jour. of Science 4th. series, vol. XIX, 1905, pp. 277-285.

LVIII, shows the position of the outcrop at the Granville mine of the Pennsylvania Glass Sand Company southeast of Lewistown, and Figure 2 that at the old Macklin mine at McVeytown. In both cases the northwest dipping limb of the synclines, whose outcrops are situated on the lower portions of the hillsides, have been thoroughly disintegrated by circulating ground waters, so that the sandstone crumbles readily to a loose sand, while the southeast dipping limbs, forming the tops of the ridges at these places, are still hard white quartzite. A number of other similar occurrences were observed in Mifflin county, some of which are referred to in a later chapter on the glass sand deposits of that county. Figure 1, Plate LIX, shows the position of the Oriskany outcrop on the northwest flanks of Jacks Mountain, just north of the North Quarry of the Keystone Works of the Pennsylvania Sand Company, northeast of Mapleton. The Oriskany outcrop in this vicinity forms a low ridge, known as Sand Ridge, on the northwest slope of Jacks Mountain, which is underlain by the hard, resistant Tuscarora quartzite. In places furthest away from the main streams flowing across the formations this low ridge disappears entirely, and there is only a slightly steeper escarpment along the northwest slope of Jacks Mountain and its northeast continuation in Standing Stone Mountain, this depression from a geologic standpoint is usually one of the most recent of the topographic features developed, so that for a long time all along the greater part of Sand Ridge the drainage from the higher ridge to the Southeast flowed across it. This outcrop, therefore, in its relation to the surface topography is very much similar to the Granville and McVeytown occurrences, and it also has been sufficiently disintegrated along the greater portion of its length to be available for glass sand. Figure 2, Plate LIX, shows a view looking northeast along Sand Ridge, from the Mapleton Quarry of the Pennsylvania Glass Sand Company. The Mapleton quarry in the Oriskany sandstone appears in the foreground at the left. The quarry back of it is in the Lewistown limestone which lies stratigraphically a short distance below the Oriskany sandstone. The Juniata river crosses the formation at nearly right angles between the two quarries. Jacks Mountain is the high ridge at the right, The bare white surface appearing in places on its flanks marks the outcrop of the Tuscarora quartzite. The valley between the Tuscarora and the Oriskany is deepest near the Juniata river and becomes less and less pronounced to the north until the next cross valley is approached. The town of Mapleton, on the south side of the Juniata river, appears to the right in the photograph. Quarries are located at intervals all along the Oriskany outcrop in this vicinity, both north and south of the river.

The position of the formation with respect to the surface to-

PLATE LIX.

Orishany Sandstone

200 feet.
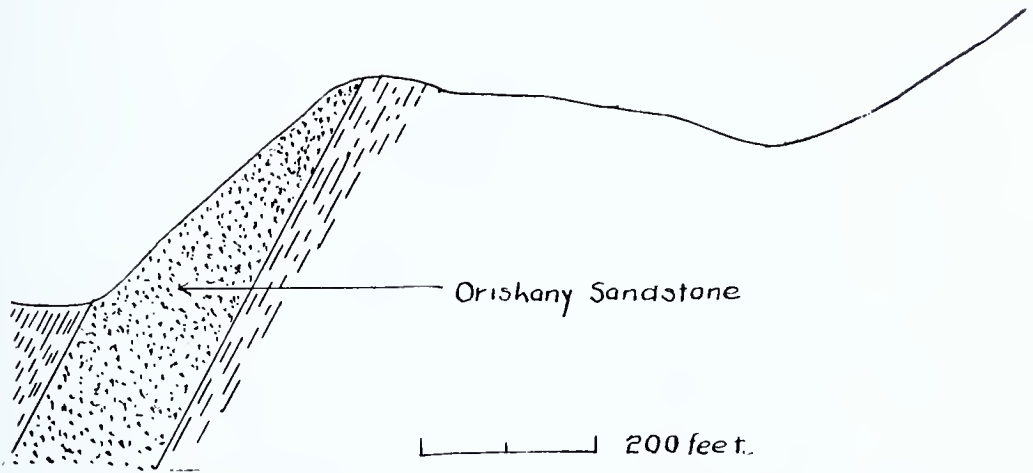
Figure 1. Cross section of Sand Ridge, north of North Quarry of Keystone Works of Pennsylvania Glass Sand Co., Mapleton, Penna.

60 feet
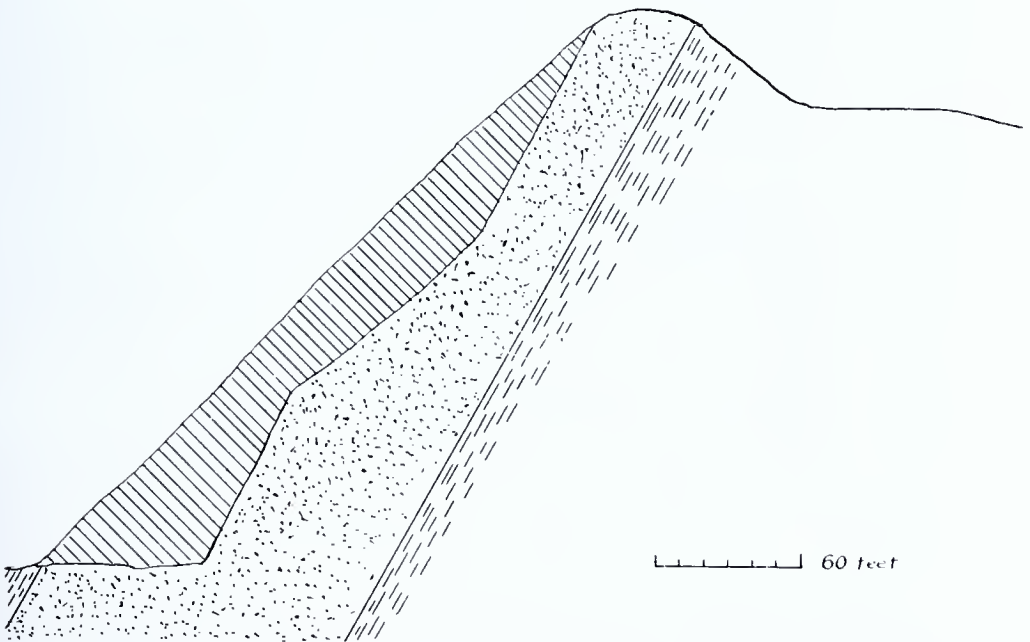
Fig. 2. Looking northeast from Mapleton Quarry of the Pennsylvania Glass Sand Co., Mapleton, Penna.

PLATE LX.

Outcrop of Oriskany sandstone north of Key-
stone Works of Pennsylvania Glass Sand
Co., Mapleton, Pa.

pography, therefore, is one important factor which determines the amount of disintegration which it has undergone. The amount of fracturing which the quartzite underwent during the crustal movements in which the region has been involved is also important, as it is along these cracks that the water first gains access to the formation. The depth beneath the surface to which the disintegration has taken place depends upon the depth to which the water could circulate with relative ease. In the vicinity of Mapleton none of the quarries have been opened below the level of the Juniata river. At McVeytown, however, in the old Dull Mine, the sandstone was found to be well disintegrated to depths of 180 feet below the level of the river at that place. It is very likely, therefore, that both at McVeytown and Granville the bottoms of the synclines formed the lower channels of circulation, towards which the surface waters tended to flow, and that, therefore, the major portion of the northwest dipping limbs have been disintegrated.

The whole of the quartzite has not always been sufficiently weathered to crush readily into loose sand. Often only a portion of the formation has been thus affected, so that in conducting quarrying operations it frequently becomes necessary to leave parts of the harder quartzite behind. At times a quarry may even have been abandoned because a poor location has been selected, where only a small portion of the exposed part of the formation has been disintegrated. This was found to be the case in the Westbrook quarry, north of Mill Creek, in Huntingdon county.

The rapidity with which the outcrop of the formation is being eroded is also an important factor in determining the amount of disintegrated sandstone available. If this is situated in such a position that it is being worn away comparatively rapidly, the weathered sandstone may be removed practically as fast as it is formed, so that the outcrop will always consist of unaltered quartzite.

There is usually a considerable contrast between the outcrop of those portions of the Oriskany which have been disintegrated in the manner described above and the portions which are still quartzite. The latter are usually marked by sharp ledges, with angular edges, and an abundance of angular boulders strewing the surface in their vicinity, while in the case of the former considerable quantities of loose white sand are usually found in their vicinity, especially on the lower portions of the slope. If ledges do crop out at the surface they have their edges rounded off and their joint planes or fractures, where disintegration has been most pronounced, have been deeply etched out by the destructive forces of nature.

Plate LX shows the Oriskany outcrop just north of the North quarry of the Keystone Works of the Pennsylvania Glass Sand Com-

pany, at Mapleton. Plate LXI, which is a nearer view of a smaller portion of the same outcrop, illustrates the rounded nature of the projecting ledge and the manner in which the joint planes have been etched out by erosion. Figures 1 and 2 of Plate LXII, taken in the same vicinity also show this feature. At this place the Oriskany is a friable sandstone which can be readily crushed to loose sand. Where detached boulders occur along the outcrop these also have their corners rounded off. This difference in the appearance of the outcrops, therefore, can often be taken as a criterion in determining whether the formation underneath has been sufficiently disintegrated for glass sand or not.

The picturesque pulpit rocks on Warriors Ridge, west of Huntingdon, along the Huntingdon-Alexandria road, shown in Figure 3, Plate LXII, and in Plate LXIII, are another example of this differential weathering. The Oriskany beds at this locality lie almost horizontal, while the joint planes are nearly vertical. Much of the sandstone here has weathered to a loose sand, unfortunately, however, too high in iron to be available for a first class glass sand. The pulpit rocks simply represent erosion remnants of the least weathered portions of the formation. They consist of more or less isolated pillars of sandstone, formed by the washing out of the loose disintegrated rock along the vertical joint planes, and to a less extent along certain of the bedding planes. They rise to heights of about fifty feet in places. Even the sandstone of which they are composed has been disintegrated sufficiently that it can be readily crushed to a loose, light brown sand between the fingers.

Practically the only deleterious impurity which is apt to occur in sands derived from Oriskany formation in central Pennsylvania is iron, in the form of limonite. This may come from two sources. Iron oxides, or occasionally such a mineral as hornblende, may have been present in sufficient amounts in the original sandstone that the sand derived from it will have too high an iron content to be suitable for glass sand, or the waters which later penetrated the sandstone and brought about its disintegration may have had iron in solution which they deposited as a thin film around the grains of quartz. The sandstone for some distance on either side of joint planes, along which such waters penetrated the rock, are frequently found to be stained brown by limonite deposited in this manner. Figure 2, Plate LV shows a thin section of such a sandstone with thin films of limonite deposited around the quartz grains, as it appears under the microscope. This section also shows that the percolating waters enter the sandstone along the contacts between the individual grains, as it was along these that the limonite was deposited. Occasionally

PLATE LXI.

Near view of Oriskany outcrop north of Keystone Works, Pennsylvania Glass Sand Co., Mapleton, Pa.

PLATE LXII.
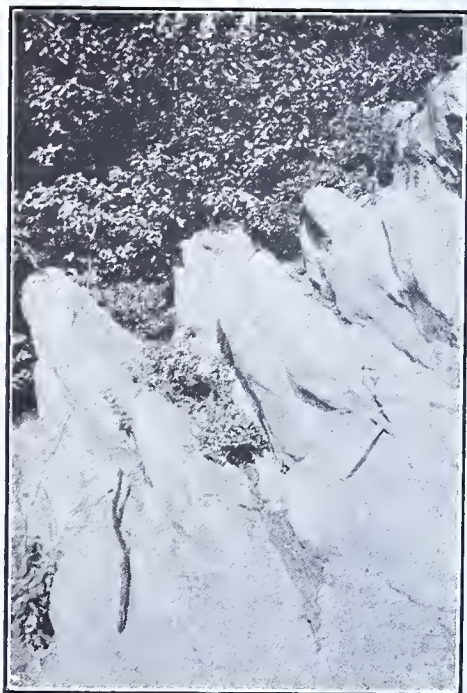
Figures 1 and 2. Near views of portions of the Oriskany outcrop north of
Keystone Works of the Pennsylvania Glass Sand Company, Mapleton, Pa.

Fig. 3. Pulpit Rocks along Huntingdon and Alexandria road, northwest
of Huntingdon, Penna.

PLATE LXIII.

Pulpit rock northwest of Huntingdon, Pa.

also a little occurs along minute cracks in the grains themselves, where the iron bearing solution had access to them.

At the outcrop the outer few inches of rock are frequently stained a yellowish brown or grayish brown by small amounts of organic matter and limonite, while further down the rock turns into a white friable sandstone. This phenomenon was observed at many localities along Sand Ridge in the vicinity of Mapleton. An anaylsis of rock stained in this manner, taken from the outcrop at the Keystone works of the Pennsylvania Glass Sand Company, showed .21% Fe_2O_3, while the white sand rock quarried at this place has the following composition.

Analysis of White Sand Rock at Keystone Works.

SiO_2,	99.76
Al_2O_3,	.14
Fe_2O_3,	.07
MgO,	none
CaO,	.28
H_2O,	.09
TiO_2,	.02
Total,	100.36

From the above discussion it is seen that the Oriskany formation of central Pennsylvania yields glass sands only in those places where the deposits consisted originally of practically pure quartz sands, which later become quartzites, and were then exposed to conditions favorable for weathering without access of iron bearing solutions. Under these circumstances friable sandstones or loose sands have resulted, which yield some of the highest grade glass sands produced in this country or abroad.

Preparation of the Sand for the Market.

At the present time, with the exception of the Granville Mine of the Pennsylvania Glass Sand Company southwest of Lewistown, in Mifflin county, and small sand mine operated by John Miller near Burnham, a suburb of Lewistown, all of the Oriskany sandstone mined for glass sand is taken out in open quarries. At Granville underground mining operations are carried on, which are described in a later chapter on the glass sand deposits of Mifflin county. In the open quarries the sand rock is blasted down, loaded onto cars and taken to washing plants, where it is crushed, dried and screened.

The methods used in preparing the sand for market by the large operators in central Pennsylvania are about the same throughout the region. Practically all of them wash and dry their sand. The sandstone as it comes from the quarry is first passed over a grizzly, consisting of a series of parallel steel bars, placed about two inches apart, on an incline. The fine material drops through the slots between the bars, while the larger pieces pass over into a jaw crusher. The material from the jaw crusher, and that which passed through

the grizzly, then goes directly to a chaser mill or wet grinding pan, which crushes the sandstone to sand. The crushed material next goes through a revolving screen, with from 10 to 12 meshes per linear inch. This separates the sand from uncrushed fragments of sandstone, which are returned to the grinding pan. The sand passes on to a battery of screw washers, where it is washed as free as possible from clayey material and limonite. It is then piled up in large cone shaped heaps and allowed to drain for about twelve hours before it is dried. Several types of dryers are employed, among which the steam dryer is the most common. After it has been dried, the sand is again screened and either loaded into cars or stored in bins for later shipment.

The above methods for crushing, washing, drying, and screening the sand have already been described in detail in Chapter V, under the head of "Silica as a raw material for the manufacture of glass." The equipment of the different plants operating in central Pennsylvania, and minor variations in the methods practiced in preparing the sand, are discussed in later chapters dealing with the individual properties. In some cases the sandstone has been sufficiently disintegrated by weathering that jaw crushers and chaser mills are not required and the sand is washed directly as it comes from the mine or quarry.

Usually the sandstone is roughly sorted into different grades in the quarry on the basis of the amount of iron stain or limonite which it shows. Only the purest portions of the rock are used for what is called Number 1 sand. In addition to this two other grades, namely numbers 2 and 3, are usually made which contain more iron. These cannot be used in the manufacture of the better grades of glass, but are available for window glass, bottle glass, etc.

Examination of Undeveloped Areas.

In determining whether a certain outcrop of Oriskany sandstone has any value as a possible source of glass sand, the first two things to investigate are whether the rock is sufficiently pure and whether it has undergone the requisite amount of disintegration by weathering to cause it to crumble comparatively readily into loose sand when put through the chaser mill. Often it is very difficult or even impossible to do this from the mere outcrop and some exploratory work is necessary to open up the deposit sufficiently to enable one to see the true nature of the rock. If small particles of the rock can be crumbled into loose sand between the fingers, the rock is sufficiently friable.

Attention has already been called to the fact that one can often obtain a pretty good idea of the nature of the sandstone from the ap-

pearance of its outcrop. If there are many projecting ledges, with sharp edges, and the surface over the outcrop is strewn with angular bolders, one is pretty safe in concluding that the underlying formation is a quartzite too hard to be economically crushed for glass sand. On the other hand if the outcrop is marked by the presence of considerable quantities of white sand and the projecting ledges have had their corners rounded off and their joint planes etched out as already described in a previous paragraph, and loose boulders of the rock overlying the outcrop are rounded instead of angular, the formation underneath, as a rule, has undergone the requisite amount of disintegration to cause it to become crushed readily into sand. Occasionally the outer few inches of rock next to the surface may be stained a grayish or yellowish brown, while the rock itself, when broken into, is found to be white and practically free from iron oxides. This must also be kept in mind when examining outcrops.

The position of the outcrop with respect to the topography of the surface, and the inclination of the beds from the horizontal are also important factors that determine the relative value of a particular occurrence of the sandstone. Upon these factors the drainage of the quarry and the amount of overburden that will have to be removed largely depend. A particular deposit of sandstone often cannot be economically worked because these conditions are not favorable. Sometimes the sandstone occurs in such a position that it can only be worked by carrying on underground mining operations. This increases the cost of production considerably and the rock must, therefore, be exceptionally pure and well disintegrated to make such an undertaking profitable.

The location of the deposit with respect to transportation facilities is another factor to be taken into consideration. Sand is a bulky material, produced with only a small margin of profit. Convenient and cheap transportation facilities to good markets are therefore, highly essential. An adequate water supply for washing the sand must also be available in the vicinity of the deposit.

Even after the above conditions have all been found to be favorable some exploratory work should be done on the deposit before any extensive plant for preparing the sand for the market is erected. If the outcrop is badly covered with overburden some of this should be removed and either bore holes with core drills, cross cuts, or shafts, should be made at intervals sufficiently close to give one an idea of the thickness and nature of the sandstone over an area sufficiently large to warrant the erection of the necessary plant for treating it. Considerable sums of money have often been wasted by erecting plants at deposits where outcrop indications alone were taken into consideration, which on further development proved misleading.

Distribution of Workable Deposits in Pennsylvania.

In Pennsylvania the Oriskany sandstone is being extensively quarried for glass sand in the vicinity of Mapleton in Huntingdon county and at Vineyard and Granville, in Mifflin county. These three places are at present the great centers for the glass sand industry in central Pennsylvania. Deposits of sufficient purity to be available for first class sand also occur in the vicinity of Everett, in Bedford county, but have not as yet been exploited for this purpose. At a number of other localities in central Pennsylvania, outside of the above areas, small quantities of Oriskany sandstone have been quarried for glass sand, but these have only been used in the manufacture of the cheaper grades of glass, such as bottle glass.

In describing the deposits of central Pennsylvania, those of Huntingdon and Mifflin couties are taken up in detail first, and then the other occurrences are referred to briefly.

Tussey Mt.

Warrior Ridge.

Sand Ridge

Jacks Mt.

Chestnut Ridge.

PLATE LXIV.

Cross section showing structure of the formations underlying Huntingdon County.
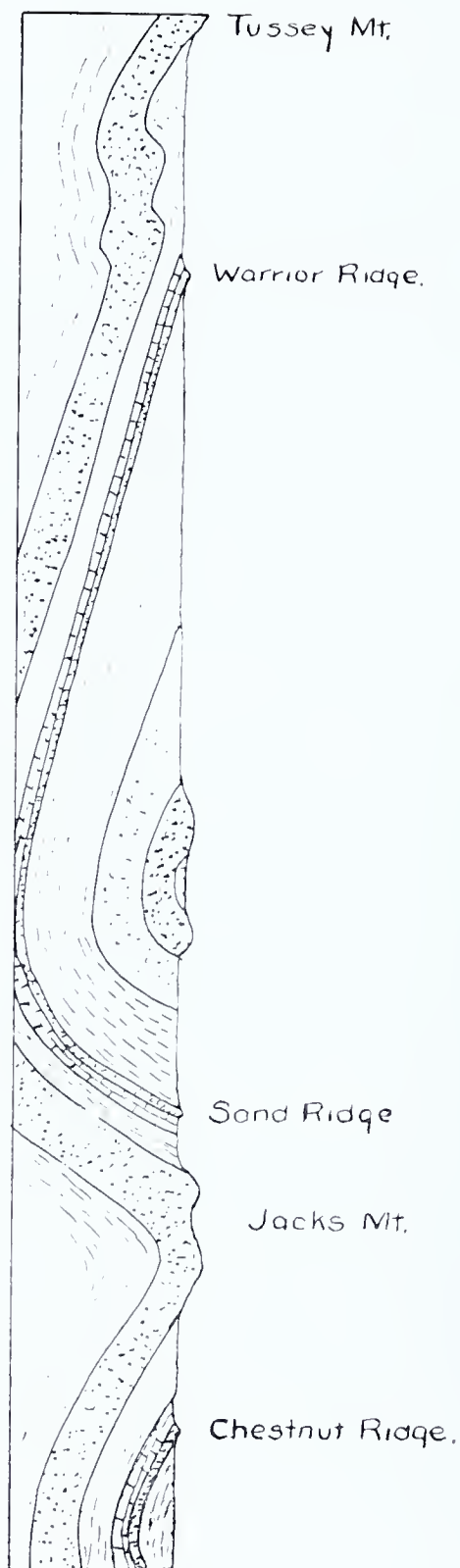
CHAPTER XVI.

GLASS SAND DEPOSITS OF HUNTINGDON COUNTY.

Location of Outcrops.

In Huntingdon county formations ranging from Ordovician through Pennsylvania age are exposed at the surface. This is due to the fact that the strata are involved in the Appalachian folding, which, as has already been stated, occurred towards the close of the Permian period. Plate LXIV is a cross section showing the structure of the formations underlying Huntingdon county. By the erosion of the arches or anticlines, formed by this folding, strata as low as the Ordovician have been brought to the surface, while in the trough or syncline between two anticlines in the southwestern portion of the county Pennsylvanian strata have been preserved to the present day. The coal deposits of the Broad Top Mountain area occur in these Pennsylvanian beds. The axes of the anticlines and synclines follow a northeasterly and southwesterly direction, with a southwest pitch. Therefore, the outcrops of the various formations follow a similar course.

In Huntingdon county the Tuscarora sandstone or quartzite of lower Silurian age, the so-called Medina sandstone of the Second Geological Survey of Pennsylvania, is the formation which is the most resistant to erosion. It is the mountain or ridge forming formation of central Pennsylvania; Tuscarora, Shade, Black Log, Jacks, Standing Stone, and Tussey Mountains marking its outcrops in Huntingdon county. At Mt. Union, Mapleton, and Three Springs, this massive white quartzite is extensively quarried as ganister for the manufacture of silica brick.

The Oriskany formation of the lower Devonian is also represented by a quartzite varying from white to bluish gray in color, but it is not as resistant to weathering as the Tuscarora, nor does it have the great thickness of the latter. For this reason, although the outcrops of the Oriskany are also usually marked by ridges, these are insignificant in height when compared with those formed by the Tuscarora. Very often they occur as minor ridges on the flanks of the latter.

In Huntingdon county the Oriskany occurs in the syncline between Tuscarora and Shade Mountains in the southeastern part of the county. Its outcrop here forms two narrow belts, one on the west side of the Tuscarora and the other on the east side of Shade mountain. In the syncline itself it is buried under Devonian shales.

12

Similarly it occurs in the syncline between Black Log and Jacks Mountain, with outcrops on the west side of Black Log and on the east side of Jacks Mountain. North of Shirleysburg several minor flexures in this syncline bring the Oriskany strata to the surface several times. The outcrop on the east side of Jacks Mountain forms Chestnut ridge. It runs in a northeast and southwest direction through Mount Union. The Oriskany formation also occurs in the broad syncline between Jacks and Tussey Mountains. Here it is covered not only by middle and upper Devonian shales and sandstones, but also by Mississippian and Pennsylvanian strata. The outcrop on the west side of Jacks Mountain in the vicinity of Mapleton is known as Sand Ridge. This outcrop joins with that of Chestnut Ridge around the southside of Jacks Mountain, on account of the southwest pitch of the Jacks Mountain anticline, and on the northwest with that along the west side of Tussey Mountain on account of the similar pitch of the syncline. This last outcrop forms Warrior Ridge in the vicinity of Huntingdon. Plate LXV is a map showing the distribution of the Oriskany outcrops in Huntingdon, Mifflin and Bedford counties.

Workable Portions of the Oriskany.

From the standpoint of economic value as a source of glass sand the outcrop of Oriskany which forms Sand Ridge is by far the most important in the county. This is the source of the glass sands quarried so extensively in the vicinity of Mapleton. The sands of Warriors Ridge have also attracted some attention as possibly being of value for the manufacture of glass, but no very extensive industry has as yet been developed along this ridge. For the location of places mentioned in the following description, reference should be made to Plate LXV and to Plate LXVI, which shows the location of the sand quarries around Mapleton.

Sand Ridge, as has already been stated, forms a low ridge along the west side of Jacks Mountain, which north of Mill Creek, (where Jacks Mountain divides into two ridges, the easterly one of which is still known as Jacks Mountain, while the westerly one goes under the name of Standing Stone Mountain), continues along the west side of Standing Stone Mountain until, in the northern part of the county, it swings to the west and joins Warriors Ridge northwest of Huntingdon.

At Mapleton a gap occurs in the ridge, as well as in Jacks Mountain, where the Juniata river crosses the formation at right angles. South of the river there is a small valley occupied by Scrub run, between Sand Ridge and Jacks Mountain. This valley has been eroded in the softer limestones and shales of the Lower Devonian and the

Burnham
Lewistown
Granville
McVeytown
Huntingdon.
Warriors Ridge
McConnellstown
Mill Creek
Vineyard
Brumbaughs Siding
Marklesburg
Mapleton
Mt Union
Sand Ridge
Hummel Sta.
Chesnut Ridge
Shirleysburg
Orbisonia
Saltillo
Three Springs
Tatesville
Everett

Oriskany Outcrop
4 Miles.
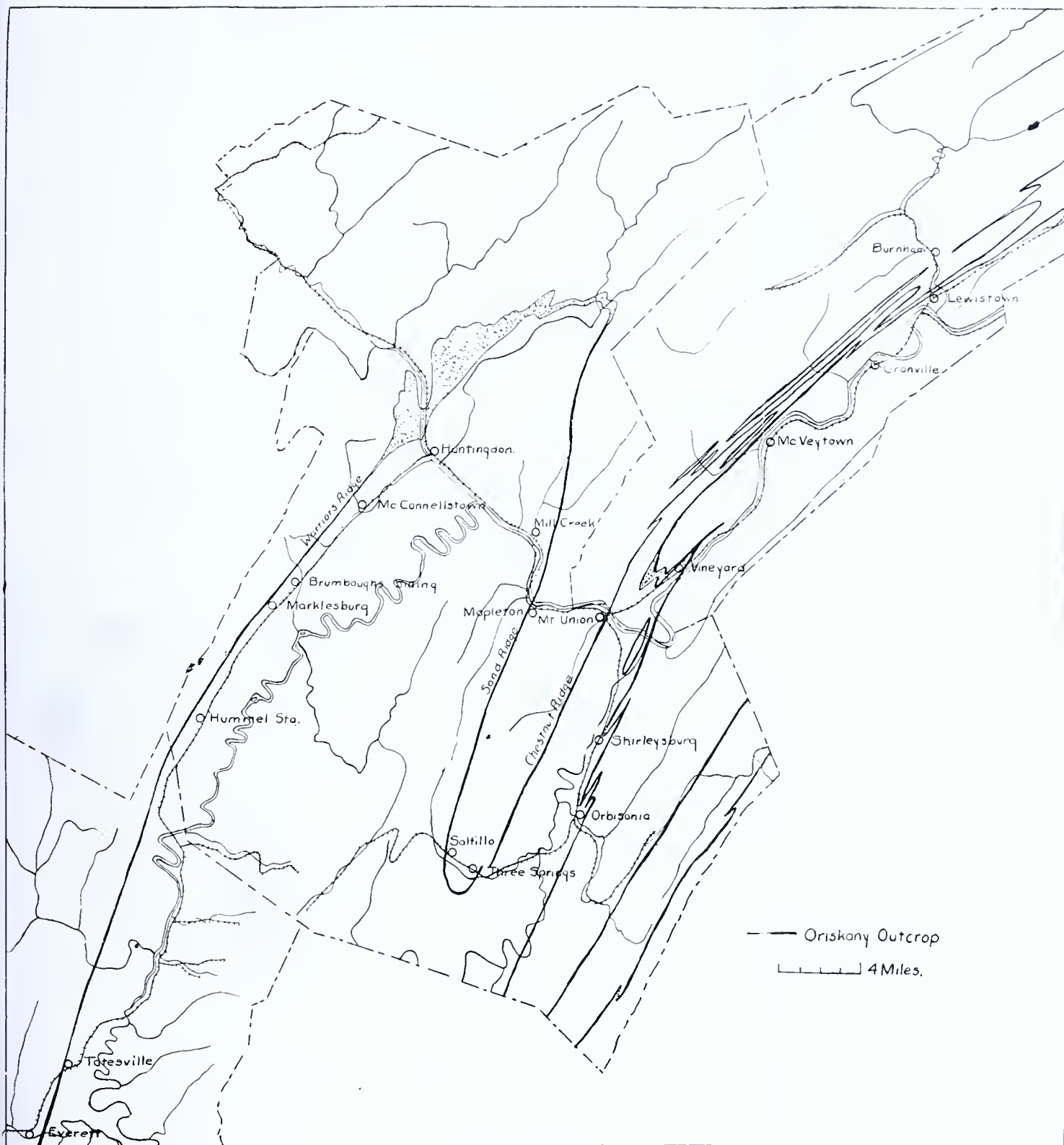
PLATE LXV.

Map showing Oriskany outcrops in Huntingdon, Mifflin and portions of Bedford counties.

Westbrook
Glass Sand Co.

Mill Creek.

Abandoned Franklin Quarry

Columbia Quarries.

Keystone Quarries.

Abandoned Empire Quarries

Abandoned Quarry.

Mapleton Depot

Abandoned
Quarry

Mapleton
Quarry

Pittsburgh White Sand Co!

Juniata White Sand Co.

Pittsburgh White Sand Co.

One Mile.
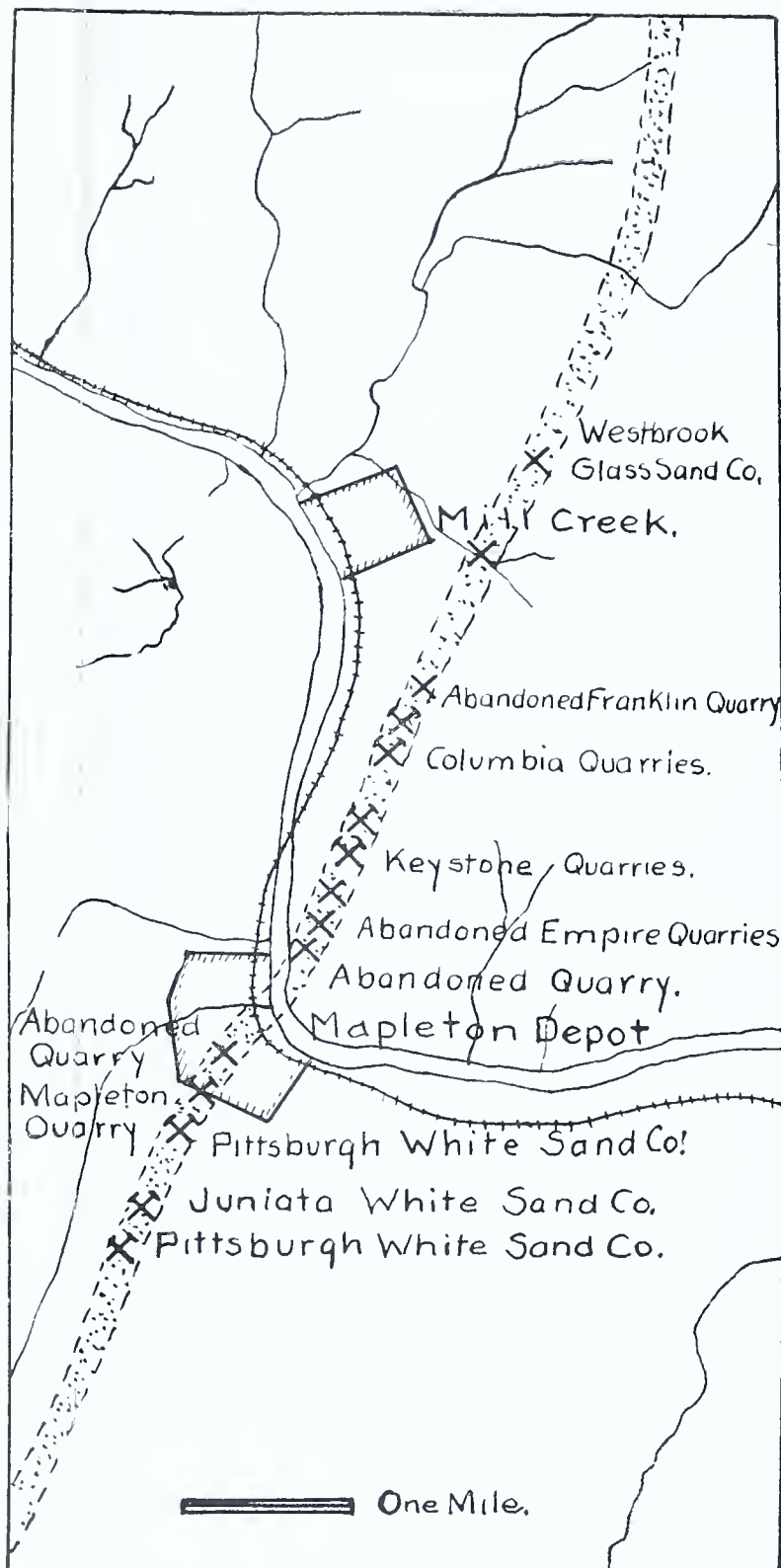
PLATE LXVI.

Map showing location of glass sand quarries in vicinity of Mapleton.

Silurian which occur between the Oriskany and Tuscarora formations. Further south this valley disappears and the Oriskany forms a low ridge on the flanks of Jacks Mountain. In places this ridge disappears entirely, although the outcrop of the Oriskany is usually marked by a rather steep cliff or escarpment on the west side. On the north side of the river similar conditions exist.

South of the Juniata River Sand ridge appears in the form of a low ridge in the town of Mapleton and gradually rises to a high, steep ridge to the southward. The nature of the rock comprising the ridge may first be studied to advantage in an old abandoned quarry on the southern margin of the town. Here the ridge has an elevation of about 130 feet above the surrounding country. The sandstone formation strikes N. 25°E, and. dips 65° to the northwest. It has undergone considerable fracturing so that joint planes are prominent. One set is nearly parallel to the bedding plane, another is parallel to the strike and nearly vertical, while a third occurs at nearly right angles to the strike and is steeply inclined. Other sets are also present but are less prominent. These fractures or joints have given access to downward percolating rain water, which has produced extensive disintegration in the sandstone. Soil is almost entirely absent from the top of the ridge and erosion has therefore etched out these joint planes, so that the outcrop is marked by a series of fantastic shaped forms, similar to those illustrated in other portions of this report.

The rock is somewhat less disintegrated than that of some of the other quarries at present operated around Mapleton. The sharp edges are still retained by the angular blocks left in the quarry face, although it has not been operated for many years as is shown by the size of the trees growing in it. When small pieces of the rock, however, are taken between the fingers they can be broken down into loose sand. A little iron oxide has been deposited in the form of limonite along some of the joints by percolating waters, and here and there little yellow specks of limonite occur in the main body of the rock itself. Otherwise it is a pure quartz sandstone which can be quite readily crushed down to a light cream colored sand.

A short distance south of the above quarry, along the ridge, is the quarry of the Mapleton works of the Pennsylvania Glass Sand Company. At the north end of the quarry the ridge rises about 120 feet above the level of Scrub run at this place, while at the south end it rises to an elevation of 165 feet. The floor of the quarry is about 50 feet above the level of the run. The formation has a strike of N 29° E, and dips 53° to the northwest. It has a thickness of 168 feet. At about the middle of the north end of the quarry a bed of conglomerate three feet in thickness is present. Some of the pebbles, which

consist entirely of quartz, have a diameter of $\frac{1}{4}$ inch, but most of them are smaller. The conglomerate is very fossiliferous. Twelve hundred feet south, at the other end of the quarry, it has a thickness of only one foot. Small pebbles are also present occasionally at other horizons in the formation at this quarry, especially in the upper portion.

The sandstone at this place has also undergone considerable fracturing. A moderate amount of iron oxide in the form of limonite has been brought in along some of the joint planes. In some cases, where the fracturing has been very intense, this limonite has penetrated the rock itself. In a few places a little black oxide of manganese in the form of dendritic growths has also been deposited along some of the joints. Portions of the rock show little rust spots consisting of limonite scattered here and there through the mass. These have evidently resulted from the weathering of some mineral in the rock which contain iron. Outside of this the rock is a pure white quartz sandstone.

On the whole, the rock has undergone considerable weathering, so that most of it can be readily disintegrated into loose sand between the fingers. There are portions of it, however, which have escaped this weathering process. These are still hard, a white to buff colored quartzite, and when encountered in considerable masses in the quarry have been left behind while the softer rock around them was removed.

The Mapleton quarry of the Pennsylvania Glass Sand Company is adjoined on the south by the North quarry of the Pittsburgh White Sand Company. At this place the Oriskany sandstone has been quarried for a distance of nearly 2000 feet along the strike. The highest ledges along the crest of Sand Ridge rise about 160 feet above the level of the present quarry floor. The formation dips $65\frac{1}{2}°$ to the northwest and has an approximate thickness of 130 feet, of which the lower 90 are being quarried at the present working face. Plate LVI shows the appearance of this face. The rock has been considerably fractured. One set of joints is practically parallel to the bedding plane, while another set has a strike of N 69° E and dips 69° to the northwest. Most of the sandstone crumbles readily to loose white sand. A screen analysis of a series of samples taken across the sandstone gave the following results:

Screen Analysis of Sand from North Quarry, Pittsburgh White Sand Co.

Through 4 mesh, on 6 mesh (.131 inches diameter),	-----	.42%
Through 6 mesh, on 8 mesh (.093 inches diameter),	-----	.73%
Through 8 mesh, on 10 mesh (.065 inches diameter),	-----	1.73%
Through 10 mesh, on 14 mesh (.046 inches diameter),	-----	1.57%
Through 14 mesh, on 20 mesh (.0328 inches diameter),	-----	2.42%
Through 20 mesh, on 28 mesh (.0232 inches diameter),	-----	7.36%
Through 28 mesh, on 35 mesh (.0164 inches diameter),	-----	18.90%
Through 35 mesh, on 48 mesh (.0116 inches diameter),	-----	47.84%
Through 48 mesh, on 65 mesh (.0082 inches diameter),	-----	14.71%
Through 65 mesh, on 100 mesh (.0058 inches diameter),	-----	2.18%
Through 100 mesh, on 150 mesh (.0041 inches diameter),	-----	.48%
Through 150 mesh, on 200 mesh (.0029 inches diameter),	-----	.37%
Through 200,	------	.42%

99.13%

In the northeast corner of the quarry, where it adjoins the Pennsylvania Glass Sand Company's property, the lower portion of the formation is somewhat harder and can only be disintegrated with difficulty between the fingers. It consists of white sandstone, with occasional specks of limonite. Under the microscope it is seen to consist of an interlocking mosaic of angular quartz grains, some of which from the distribution of inclusions in them, appear to have been originally rounded. Some of the quartz grains show undulatory extinction between crossed nicols. Many of them contain minute dust like inclusions, while in others rutile needles and minute prismatic crystals of apatite are visible. One well rounded grain of hornblende was observed. The occasional specks of limonite in the sandstone are probably due to the weathering of scattered grains of this mineral in the rock.

Between one-third and one-half mile further south along Sand Ridge is the quarry of the Juniata White Sand Company. This quarry has been opened for a distance of 300 feet along the strike. The formation dips 63° to the northwest and the sandstone has a thickness of about 150 feet. The surface of the highest sandstone outcrop along the top of the ridge rises 160 feet above the level of the quarry floor. The most prominent set of joints is parallel to the bedding plane. The cross joints have a strike of N 42° E and dip 70° N. W. The sandstone is white in color, except where it has occasionally been stained brown for several inches on either side of a joint plane by infiltering iron bearing solutions which have precipitated limonite between the quartz grains. Here and there portions of the sandstone have scattered through them minute specks of limonite. A thin section of such a specimen under the microscope showed one well rounded grain of hornblende to be present which seems to point to this mineral as being responsible for the brown spots disseminated through the rock, since limonite is one of the alteration products of hornblende when the latter undergoes weathering. The hardest rock present in this quarry can only be disintegrated with difficulty into

sand between the fingers. Much of the rock however, crumbles readily into white sand.

About one-quarter mile south of this quarry, along Sand ridge, the Pittsburgh White Sand Company is opening up a new quarry. At the time of the writer's visit in 1914 no very great thickness of sandstone had yet been opened by the quarrying operations, which were still confined to the upper portions of the formation. The sandstone is somewhat harder than that exposed in the other quarries along Sand Ridge, south of Mapleton, it being possible to crush only small fragments of it with difficulty between the fingers. The sandstone is white in color, except where it has been occasionally stained by a little limonite along a plane of fracture.

The South quarry of the Pittsburgh White Sand Company is the last opening in the Oriskany sandstone of Sand Ridge south of Mapleton. The outcrop continues in a southwesterly direction beyond Saltillo, which is about 12 miles from Mapleton, where it swings around the southern end of Jacks Mountain and becomes Chestnut Ridge along the east side of the latter. Beyond the South quarry of the Pittsburgh White Sand Company Sand Ridge begins to stand out less prominently, due to the gradual disappearance of the valley between the outcrops of the Oriskany sandstone and the Tuscarora quartzite of Jacks Mountain. In places the Jacks Mountain slope continues uninterrupted across the Oriskany outcrop to Hare's Valley. Usually, however, even in these cases, there is a little steeper slope on the west side, or down hill side, of the Oriskany outcrop.

As a rule the outcrops of sandstone are not as prominent as they are further to the north in the vicinity of Mapleton. Rounded boulders occur along the outcrop and here and there masses of the sandstone which are in place. From their appearance they indicate that the underlying formation is probably well disintegrated by weathering. The position of the outcrop on the west slope of Jacks Mountain insures a good supply of surface drainage, much of which has an opportunity to penetrate the sandstone formation, making conditions ideal for its disintegration to a sufficient degree to make it available for glass sand. Pieces of the sandstone chipped from surface boulders and projecting masses of the sandstone usually have a brown or brownish gray color, due to stain by limonite and organic matter. This cannot be taken as indicating that the underlying rock contains too high an iron content to yield a good glass sand, however, because, as has already been stated, the outcrops of some of the best sand rock north of Mapleton have the same appearance. The true nature of the rock can only be determined by carrying on some exploratory work beneath the surface.

PLATE LXVII.
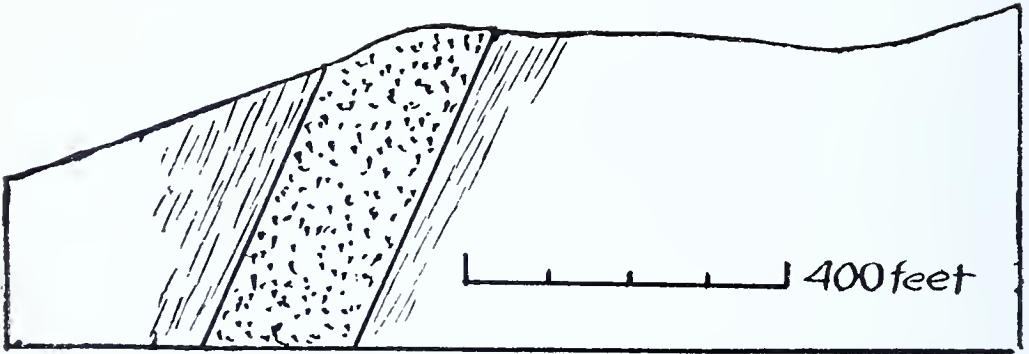
Fig. 1.   Cross section of Sand Ridge one quarter mile south of South Quarry
of Pittsburgh White Sand Company, Mapleton.
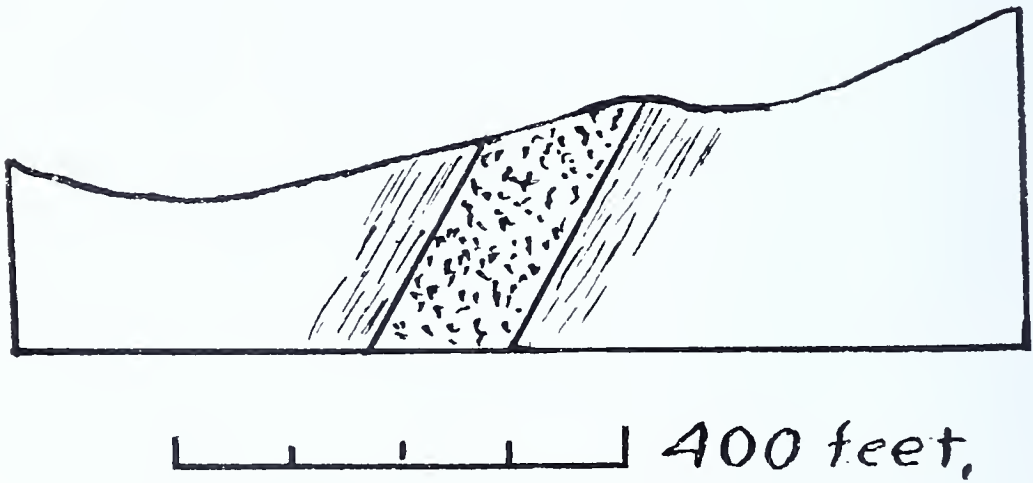
Fig. 2.   Cross section of Sand Ridge three miles north of Saltillo.

About one-quarter mile south of the South Quarry of the Pittsburgh White Sand Company the profile shown in Figure 1, Plate LXVII was made to show the position of the Oriskany sandstone with respect to the surface topography. The sandstone has a thickness of 170 feet at this place. The valley between it and the Tuscarora quartzite of Jacks Mountain has practically disappeared. One disadvantage in conducting quarrying operations here would be the comparatively large amount of overburden which would have to be removed from the hanging wall before operations could proceed. The formation dips 67° to the northwest. Indications upon the surface are that the sandstone underneath is sufficiently friable for crushing into glass sand.

About 5½ miles southwest of Mapleton, just south of the place where the road through Singers Gap crosses Jacks Mountain, Sand Ridge is again marked by a rather rugged outcrop, similar to that in te vicinity of Mapleton, with many isolated pinnacles of sandstone projecting above the main mass. The beds dip 55° to the northwest, and about 110 feet of sandstone are exposed. The upper portion of the formation contains some pebbles up to one-quarter inch in diameter. The lower portion is free from these. All of the outcrop rock can be crushed into sand between the fingers. It usually has a brown color when chipped off from the surface. Occasionally some limonite occurs along fractures in the rock, but as a rule this does not penetrate the sandstone itself. Surface indications at this place are favorable, but, as has already been mentioned in other cases, some exploratory work is necessary before any positive statement as to the value of the sandstone for glass sand can be made.

About three miles north of Saltillo the formation has a thickness of about 110 feet, and dips 60° to the northwest. It has been pretty well disintegrated, judging from outcrop indications. The projecting ledges and loose boulders are well rounded and considerable white sand lies about on the surface. Figure 2, Plate LXVII, shows the position of the outcrop with respect to the surface. Prominent ledges of sandstone occur along the hanging and foot walls, with very little rock exposed between. This indicates that the middle portion of the formation has probably been more thoroughly weathered than the upper and lower. From outcrop indications the formation at this place, with the exception of a few feet of the lower portion, is comparatively free from iron.

To the south of the above outcrop the formation looks less promising as a possible source of glass sand. Where the Hare's Valley road crosses the outcrop, about one-half mile north of Saltillo, there is a small opening on the formation on the north side of the road. The sand exposed is very argillaceous and the boulders of sandstone in

it do not appear promising on account of their high limonite content. Only talus material, however, has been penetrated.

In the vicinity of Saltillo the Oriskany sandstone forms a distinct ridge separated from Jacks Mountain by a wide valley, the former lying to the west while the latter lies to the east of the town. In places along the former the sandstone has been weathered to a loose sand, but in other places it is still a hard quartzite, judging from the surface boulders occasionally seen along the outcrop. Where it has weathered to a sand this is stained light yellowish brown by limonite, and in places contains considerable clayey material. It would not yield a first class glass sand even on washing.

North of Mapleton, Sand Ridge stands out very prominently, rising to a height of from 180 to 260 feet above the river, with a steep escarpment along the northwest side. The appearance of the ridge here is well shown in Plate LXVIII, which is a view taken at the quarries of the Keystone works of the Pennsylvania Glass Sand Company north of Mapleton, looking east. The valley between the Oriskany sandstone outcrop of the Sand ridge and the Tusarora quartzite of Jacks Mountain is only pronounced where valleys have been cut at right angles by streams through Sand Ridge and developed tributaries parallel to the strike of the formations in the softer shales and limestones between the two sandstones. The profile of the ridge shown in Figure 1, Plate LIX, was made a short distance to the left of the quarry appearing near the center of the picture in Plate LXVIII.

The first quarry along Sand Ridge north of Mapleton is situated at the point where the Oriskany sandstone outcrop again rises as a ridge north of the gap formed by the Juniata river. The formation here dips 61° to the northwest and is fossilferous throughout its entire thickness. Underneath it a fossilferous sandy shale is exposed. Fracturing is pronounced, the most prominent set being very nearly parallel to the bedding planes. The sandstone here is comparatively hard, only small portions of it crumbling readily into sand between the fingers. Most of it is white to light cream yellow in color, with occasional portions showing scattered specks of limonite.

Adjoining this quarry on the north is the South quarry of the Empire works of the Pennsylvania Glass Sand Company. This plant has been dismantled and the quarry, therefore, is not being operated at present. The sandstone at this place dips about 58° to the northwest, and has an approximate thickness of 130 feet, of which the upper half was quarried. The sandstone on the whole is white in color, except where occasionally a little limonite stain occurs in it along a joint plane. About one-third of it crumbles readily to sand in the hand, while the rest can be crushed between the fingers when small fragments are broken off. About 500 feet beyond is the North quarry
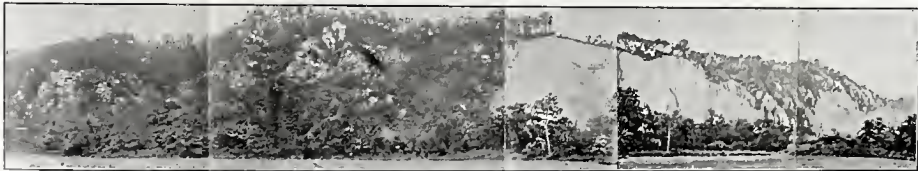
PLATE LXVIII.

Sand Ridge in vicinity of Keystone Works of Pennsylvania Glass Sand Company, north of Mapleton.
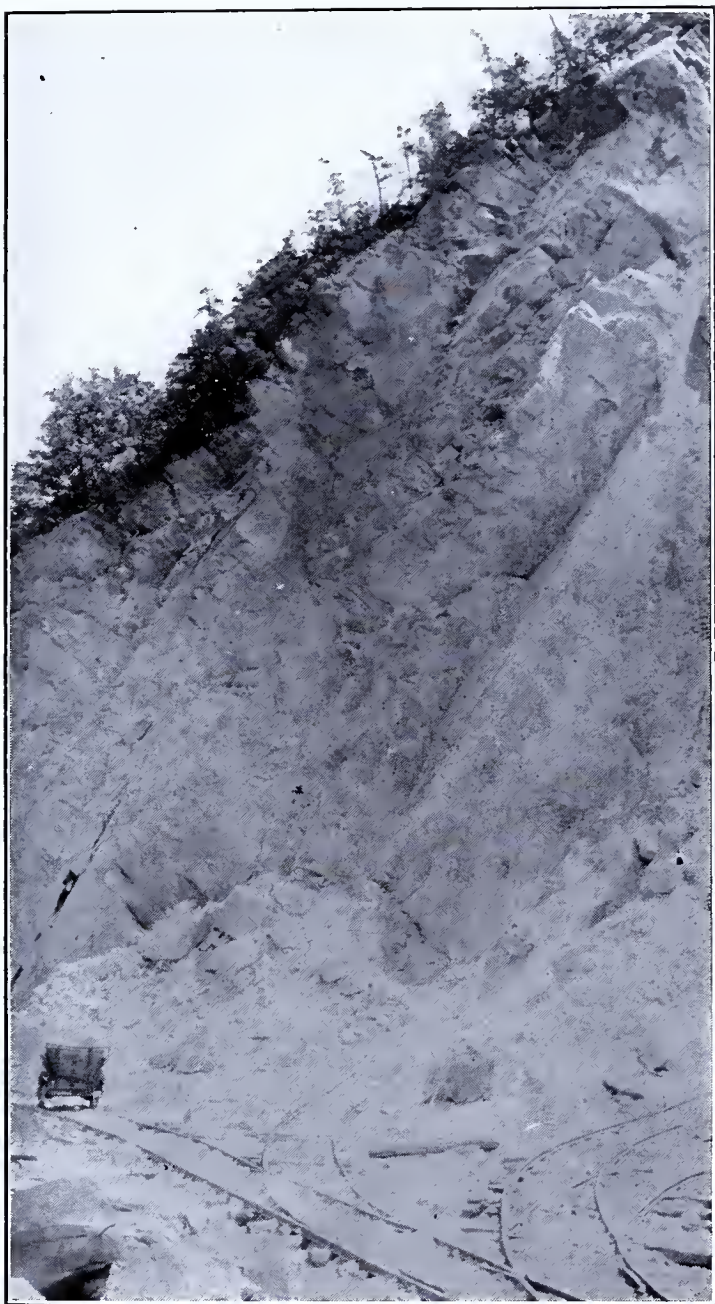
PLATE LXIX.

Portion of northeast working face at North Quarry of
Keystone Works of Pennsylvania Glass Sand
Co., at Mapleton, Pa.

of the same works, also abandoned at present. Here the sandstone dips 65° to the northwest, and has an approximate thickness of 125 feet, of which the upper 70 feet were quarried. This quarry has been opened for a distance of 280 feet along the strike. The ridge rises to an elevation of from 180 to 200 feet above the level of the Juniata river. The sandstone here has a white color and can be crushed to sand between the fingers. Along some of the fracture planes disintegration to loose sand has occurred, which usually has a light cream yellow color due to the infiltration along the joints of small amounts of iron in solution.

About 700 feet north of this opening is the South Quarry of the Keystone Works of the Pennsylvania Glass Sand Company. This quarry, at the time of the writer's visit in 1914, had a length of about 300 feet, along which the upper 80 feet of sandstone had been quarried for glass sand. The rock is of an excellent quality, only moderately hard and pure white in color. Very little iron stain occurs along the joint planes. The following analysis shows the chemical composition:

Analysis of Glass Sand from South Quarry, Keystone Works, Mapleton, Pa.

SiO_2,	99.76
Al_2O_3,	.14
Fe_2O_3,	.07
MgO,	none
CaO,	.28
H_2O,	.09
TiO_2,	.02
	100.36

The North Quarry of the Keystone Works is 300 feet further on along the ridge. It has been opened for a distance of 690 feet along the strike. The formation has a thickness of about 130 feet. In one place the foot wall has been broken through and a large amount of shale has run into the quarry, causing considerable inconvenience. The quality of the rock is the same as that taken out in the South Quarry. At the southwest end a streak of cream colored sand was encountered near the foot wall. The two quarries are shown in Plate LXVIII, the North Quarry being the one near the center of the photograph, while the south one is at the right. The sandstone runs up to the top of the ridge, which rises about 240 feet above the level of the Juniata River flood plain shown in the foreground. Figure 1, Plate LIX, shows a cross section of the ridge made about 250 feet to the left of the center quarry. Plate LXIX shows the appearance of a portion of the northeast working face of this quarry at the time of the writer's visit.

The next opening along Sand Ridge is the South Quarry of the Columbia Works of the Pennsylvania Glass Sand Company, situated about one and two-thirds miles northeast of Mapleton. This quarry

is located on the north side of a small creek which has cut a valley across Sand Ridge at this place. Figure 1, Plate LXX shows a view of the quarry looking northeast along the strike. The Oriskany formation here dips 62° to the northwest and has a thickness of about 200 feet. The top of the ridge rises 110 feet above the floor of the quarry. The sandstone here is also pure white in color but somewhat harder than that encountered at the Keystone quarries. Most of it cannot be crushed to sand between the fingers. It is badly fractured as the view of the quarry shows.

About 700 feet north of this quarry the Pennsylvania Glass Sand Company has recently opened up another quarry to supply the Columbia Works with sandstone. At the time of the writer's visit only the upper portion of the sandstone had been exposed. The rock is also white in color and is more friable than that encountered at the South Quarry. Much of it can be readily crushed between the fingers.

Less than one-quarter mile northeast of the Columbia Works, on the south side of another small creek which has cut a valley across Sand Ridge, is located the Franklin quarry of the Pennsylvania Glass Sand Company. The mill which was supplied with sandstone from this quarry was dismantled a number of years ago and the quarry is, therefore, not operated at present. Figure 2, Plate LXX, shows a view looking southwest along the strike in this quarry. The sandstone has a thickness of 120 feet and dips 62° to the northwest. The lower few feet and the upper portion of the formation are quite hard and were left behind, only the lower 65 feet being quarried. This part is fairly friable and crumbles readily to sand. The rock is white in color. About 500 feet of the formation have been removed along the strike. The ridge rises about 150 feet above the floor of the quarry and on top is fairly level, forming a terrace on the west slope of Standing Stone Mountain.

Continuing northeast along Sand Ridge another valley cuts across it east of the town of Mill Creek. On the north side of this valley the Westbrook Glass Sand Company opened a quarry, which was abandoned when its plant at Mill Creek was dismantled. The sandstone at this place has a thickness of about 125 feet, and dips 65° to the northwest. Most of the rock exposed in this quarry consists of a bluish grey quartzite, too hard to be economically crushed to glass sand. Where slight leaching has occurred along fractures it has been turned white in color, but it is still a quartzite.

About 4,000 feet northeast of this locality the Westbrook Glass Sand Company opened another quarry along Sand Ridge. Conditions encountered at this quarry have already been described in Chapter XV, under the head of secondary changes necessary in the Oriskany sandstone to render it suitable for glass sand. Figure 1, Plate LVII,

PLATE LXX.

Fig 1. Looking northeast in the South Quarry of the Columbia Works of
the Pennsylvania Glass Sand Company at Mapleton.

Fig. 2. Looking southwest in the abandoned quarry of the dismantled Franklin
Works of the Pennsylvania Glass Sand Company at Mapleton.

shows a cross section of the quarry and figure 2 is a view taken in the quarry. The formation also has a thickness of about 125 feet at this place and dips 60° to the northwest. Leaching has only proceeded to a depth of from 25 to 30 feet beyond the exposed surface of the sand-stone. When this was removed along the face of the cliff formed by the outcrop a white to bluish gray quartzite was encountered which has already been described. The ridge rises to an elevation of about 225 feet above the floor of the quarry which was opened up for a distance of 200 feet along the strike. The following two analyses give the composition of the quartzite and the white sand derived from it by weathering:

<div align="center">Analyses of Quartzite and Sand from Near Mill Creek.</div>

	Bluish gray quartzite.	Sand derived from quartzite by weathering.
SiO_2,	99.39	98.75
Al_2O_3,	.30	.52
Fe_2O_3,	.12	.03
MgO,	none	none
CaO,	.29	.28
H_2O,	.17	.17
TiO_2,	.03	.03
Total,	100.30	99.78

A careful examination of the outcrop at this locality with those features in mind which indicate considerable disintegration of the underlying rock would have shown that the rock would very likely be too hard for economically crushing into glass sand. Such an investigation would have saved a considerable sum of money spent in the erection of a plant, which later had to be abandoned. The outcrop is marked by prominent ledges cropping out at the surface. Joint planes are not deeply nor widely etched out. Along the top of the ridge large masses of loose boulders occur, many of which are quite angular, although some are partially rounded. Along the steep cliff on the west side, where very little soil is present, the rock is sometimes a quartzite at the surface.

About one mile northeast of the Westbrook Quarry, Saddler Run has cut a wide gap in Sand Ridge. South of the gap the ridge rises sharply, with steep slopes on either side. No prominent pinnacles of Oriskany sandstone project, however, the outcrop being simply marked by more or less isolated boulders. Some of these are almost white in color, but most of them are stained a light yellowish brown or gray-ish brown by limonite and organic material. Chips from these boulders can be crushed to sand in the hand.

North of the Saddlers Run gap, Sand Ridge again rises to an ele-vation of 235 feet above the level of the run and continues along the

northwest slope of Standing Stone Mountain, in some places as a separate ridge on the slope of the latter, while in other places merely as a somewhat steeper escarpment on the west side, near its base. At a number of places where the outcrop was examined by the writer it looks favorable as a possible source of glass sand, but no definite statement can be made without some preliminary exploratory work. Figure 1, Plate LXXI, shows a profile of the ridge made about 3½ miles north of Mill Creek. The formation dips 60° to the northwest at this place and about 80 feet of sandstone are exposed. The outcrop is very prominent, there being many isolated pinnacles projecting along the ridge. Some of the outcrop rock is pure white in color, although most of it is stained somewhat by limonite and organic matter. There is also considerable loose white sand on the slopes below the crest of the ridge. On the whole this portion of the ridge appears favorable as a possible site for a glass sand quarry.

Continuing northward the Oriskany outcrop makes a broad curve in northern Huntingdon county, until, northwest of the town of Huntingdon, it becomes Warriors Ridge, which then continues in a southwesterly direction into Bedford county. Between Sand Ridge and Warriors Ridge the Oriskany is covered by a thick series of Devonian, Mississippian, and in the southern part of Huntingdon County by Pennsylvanan strata, which have been preserved from erosion in a broad synclinal basin pitching toward the southwest.

West of Huntingdon the Oriskany has a very broad outcrop, due to the fact it has only a very slight dip to the southeast and several minor flexures are present in the stratta. Where the Juniata River crosses Warriors Ridge through a gap the sandstone is well exposed on both sides of the River. Most of it consists of a light buff colored quartzite. In thin section, under the microscope, it is seen to be made up of an interlocking mosaic of irregular shaped quartz grains, with occasionally a little iron oxide between them. Dust like inclusions are abundant in many of the grains, while others have needles of rutile or minute prismatic crystals of apatite. From the distributions of the inclusions in them some of the grains show that originally they had a rounded outline.

On the southwest side of the river, along the top of the ridge, which is broad and fairly level with only minor valleys, the quartzite at numerous places has been disintegrated sufficiently by weathering to cause it to crumble readily into sand. The pulpit rocks of this region have already been referred to in Chapter XV, under the head of secondary changes in the Oriskany sandstone. A number of sand pits have been opened in the Oriskany on Warriors Ridge along the Huntingdon-Alexandria road, northwest of Huntingdon, but this sand is only used at present for building purposes in the neighborhood, be-

PLATE LXXI.
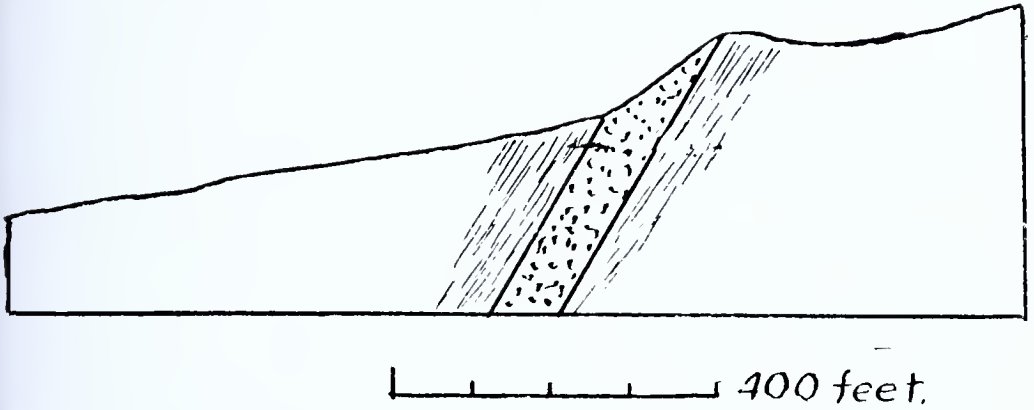
Fig. 1. Cross section of Sand Ridge 3½ miles north of Mill Creek.

Fig. 2. Abandoned quarry in Oriskany sandstone at McConnellstown.

ing hauled to Huntingdon in wagons. The first quarry along this road is that of E. C. Jones. It is located about one and one-half miles northwest of Huntingdon, a little northeast of the main highway. The working face is about 240 feet long and 20 to 25 feet high, with one or two feet of surface soil. The sandstone for the most part has become disintegrated to a loose cream colored sand, too high in iron to be available for glass making. A few boulders of sandstone are still present in this sand, which require crushing. These are thrown aside at present. Not far beyond, and also on the northeast side of the road a similar sand bank has been opened by Scott Hewitt for supplying Huntingdon with building sand. A few hundred feet beyond is the sand bank of John Schulz. Most of the sandstone at this place also disintegrates readily into a loose light yellowish brown sand, which can be shoveled into wagons. Some rock is also present which would require crushing and is, therefore, thrown aside at present. This rock is usually nearly white when broken into. In summarizing it may be said that no deposits have been opened up along this portion of Warriors Ridge which could be marked as first class glass sands.

Southwest of Huntingdon, at McConnellstown, a stream has cut a gap through Warriors Ridge. On the south side of this gap a quarry was operated in the Oriskany sandstone to supply the Colonial Iron Company of Riddlesburg with furnace sand. At present it is idle. At this place the formation has a thickness of 60 feet and dips 19° to the southeast. The upper portion contains very little iron and crumbles readily to a very light cream yellow sand. Parts of this should yield a fairly good quality of glass sand. The lower half, on the other hand, is badly stained by limonite. Figure 2, Plate LXXI, is a view taken in this quarry looking southwest. The ridge rises about 75 feet above the bottom of the quarry and is covered by from two to three feet of soil.

Continuing southward along Warriors Ridge the next opening encountered is that of the Standard Sand Company at Brumbaugh's Siding. At the time of the writer's visit in 1914 this property was also idle. The sandstone has a thickness of 85 feet and dips 20° to the southeast. It has undergone considerable disintegration so that it crumbles readily into loose sand in the hand. Most of it contains a good deal of argillaceous or clayey material and practically all of it is discolored by limonite to a yellowish brown. The upper portion of the formation contains the least amount of iron. No first class glass sand can be produced at this place and it is doubtful if even a No. 2 sand could be obtained by washing. From the equipment of the plant erected at the quarry it is evident that no attempt was made to produce any glass sand, as this consists simply of a jaw

crusher, dry grinding pan and revolving screen, with the necessary elevators to handle the sand, and a boiler and engine to run the machinery. Figure 1, Plate LXXII, shows a view of this quarry. It has been opened up in two benches, the upper one of which has a depth of from 3 to 20 feet, consistiing largely of strippings, while the floor of the lower one is 16 feet below that level.

At Marklesburg, along the north side of the road leading to the west, a sand bank for local use has been opened on the north side of the road on the property of H. B. Brenneman. The Oriskany in this vicinity has a very flat dip, this being only about 4° to the southeast. As a result the outcrop is wide. It has been opened up for a horizontal distance of 420 feet at right angles to the strike. At present the main quarry has a working face 240 feet long and varying in height from 20 to 25 feet, with one to two feet of soil. The rock is all thoroughly disintegrated and crumbles readily to sand in the hand. Considerable argillaceous material is present and it is rather badly stained by limonite, which renders it unfit for glass making purposes. Figure 2, Plate LXXII, shows the appearance of this quarry.

South of Marklesburg the Oriskany sandstone has not been disintegrated to loose sand at all places along Warriors Ridge. North of Hummel Station, where it rises as a very prominent topographic feature to an elevation of nearly 300 feet above the level of the valleys on either side, it consists of a hard, buff colored, quartzite. At Hummel Station and for some distance to the south it has again undergone considerable weathering, so that it crumbles comparatively readily into sand.

At Hummel Station on the southwest side of the gap through the ridge, which is comparatively low at this place, the Hummel Sand Company has opened a quarry in the Oriskany sandstone from which they intend to ship some glass sand. Seventy-five feet of sandstone are exposed. The dip is 38° to the southeast. At the time of the writer's visit, in August 1914, exploratory work had not yet proceeded very far so that the formation was nowhere exposed more than ten feet below the surface. The lower portion of the formation is the most disintegrated. Considerable loose sand of a yellowish brown color is present, with masses of readily crushed sandstone, usually stained somewhat with limonite, imbedded in it. The upper portion is firmer. Considerable fracturing has occurred and some discoloration by limonite along the joints thus developed has taken place. Much of this rock has a white color, although often when blocks of apparently white sandstone are broken into discoloration by limonite is found on the inside. The upper ten feet of the formation have very coarse texture. The type of rock thus far opened up at this place will yield only a second class sand on washing.

PLATE LXXII.

Fig. 1.   View in quarry of Standard Sand Company at Brumbaugh's Siding
south of McConnellstown.

Fig. 2.   View in quarry on farm of H. B. Brenneman at Marklesburg.

Not far beyond the above quarry Warriors Ridge passes into Bedford County. It is therefore referred to again in the discussion of the sand deposits of that county.

Along Chestnut Ridge, on the east side of Jacks Mountain, the Oriskany sandstone does not crop out at the surface in the form of prominent ledges. Usually the outcrop is marked simply by loose boulders of sandstone along the top of the ridge, with occasionally a projecting mass of the formation itself. At Mount Union its thickness is 95 feet, with a dip of 24° to the southeast. At Three Springs, where it is exposed in the railroad cut, the thickness is 75 feet and the dip 35° to the southeast.

Nowhere along Chestnut Ridge, so far as observed by the writer, does the outcrop have an appearance indicating that the underlying sandstone might be suitable for glass sand. The boulders of loose rock are usually only moderately rounded and are fairly hard. Where the formation itself crops out at the surface this is often a bluish gray quartzite. Mr. I. N. Swope of Huntingdon, informed the writer that the attempt was at one time made to quarry the sandstone of Chestnut Ridge for glass sand on the northeast side of the Juniata river, near the railroad bridge, but that the enterprise was abandoned because too much calcareous material occurred in it. The writer made a number of thin sections of the sandstone from the least altered rock found along Chestnut Ridge at various places, but in no case was he able to detect any calcite in them under the microscope. It, therefore, seems more likely that the attempt was abandoned because the rock was found to be too hard to crush economically.

Between Jacks Mountain and Black Log Mountain the Oriskany sandstone is covered by later Devonian strata in another southwesterly pitching syncline. Oriskany outcrops occur again on the west side of Black Log Mountain. Attention has already been called to the fact that north of Shirleysburg several minor flexures in this syncline bring the Oriskany sandstone to the surface several times. The writer did not have sufficient time to examine the whole outcrop of this region in detail. From observation made, however, it was seen that much of the formation was still a hard quartzite at the surface. At a number of places, however, weathering to friable sandstone and even loose sand has occurred.

One of these occurrences is located one and one-half miles northeast of Shirleysburg, along the road up Fort Run valley, on the property of David Gumbert. Here along the southeast side of the road there is an opening about 30 feet wide and 15 feet high, from which sand has been taken for local use largely for building purposes. The Oriskany formation, which dips 50° to the northwest at this place, has become disintegrated into a loose cream colored

sand. South from this opening the ridge formed by the Oriskany rises to an elevation of about 95 feet above the level of the road. The entire thickness of the formation is not exposed and for this reason could not be determined. Very likely, however, a considerable deposit of sand is present, but from present exposures indications are that it would not be suitable for anything better than a second class glass sand, even after washing.

About one mile northeast of Orbisonia, along the road leading up the valley on the west side of Black Log Mountain, not far north of the place where the creek has cut a gap through Sandy Ridge, which is underlain by the Oriskany, disintegration has also gone on to such an extent that much of the sandstone near the surface is a loose sand. Several openings have been made along the outcrop to supply the local demand for sand. The sand exposed varies from a light gray, through cream, to light yellowish brown in color, and should on washing readily yield a second class sand. From surface indications a considerable deposit of it seems to be present. Along the sand ridge southeast of Orbisonia, on the south side of Black Log Creek gap, another opening has been made to supply sand for concrete. The sandstone at this place, with the exception of a hard ledge along the upper portion of the formation, also crumbles readily into a light yellow sand.

The outcrop along the southeast side of Shade Mountain and the northwest side of Tuscarora Mountain were not examined. Even if good glass sand deposits are there they would not be available at present for lack of transportation facilities.

History of the Glass Sand Industry in Huntingdon County.

The first glass sand from the Mapleton district was shipped in 1852. At that time the sand rock as taken from the quarries was shipped direct to the glass factories without any further treatment. After a time crushers were introduced and still later the practice of washing and drying the sand came into vogue.

In 1876 two quarries were opened along Sand Ridge, south of the Juniata river, one in the borough of Mapleton and the other in Union township, just south of the borough limits. The one in the borough called the South Side Sand Quarry, was operated by Samuel Hatfield, Jr. It is at present owned by the Pennsylvania Glass Sand Company. The other, named the Glendower Sand Quarry, was opened by the J. M. Maguire Company, but was purchased in the autumn of 1881 by Dull, Wilson and Gray. In 1883 about 15 men were employed at each of these quarries and the aggregate monthly shipments amounted to 100 car loads of sand. At present the latter quarry is operated by the Pittsburgh White Sand Company. This Company

has recently opened another quarry farther to the south along the ridge. South of the first quarry of the Pittsburgh White Sand Company the Juniata White Sand Company also has a quarry in operation at present.

At the time Report T of the Second Geological Survey of Pennsylvania was published (1885) the first quarry along Sand Ridge north of Mapleton had already been abandoned. At the present site of the Keystone Works of the Pennsylvania Glass Sand Company, B. F. Faust and Son operated a quarry. The rock at that time was first burnt and then crushed, dry, with a stamp machine, without washing. The present South Columbia quarry of the Pennsylvania Glass Sand Company was operated by J. W. Mattern. Only the lower portion of the formation was used. About 20 to 25 tons of sand were shipped daily, largely to Pittsburgh factories. The abandoned Franklin Quarry of the Pennsylvania Glass Sand Company was then owned by the Juniata Sand Company, which produced a second class sand for bottles, fruit jars, and window glass, from the lowest 30 feet of the sandstone, which are the purest and most friable. A steam crusher and washer were used to prepare about 35 tons of sand daily for shipment to Pittsburgh, Wheeling, Bellaire and other glass centers.

The Westbrook Glass Sand Company operated a two pan mill of about 300 tons daily capacity for a time at Mill Creek, but on account of the hard quartzite nature of the rock in its quarry, the project was abandoned several years ago.

Description of Glass Sand Quarries and Plants Now in Operation.

In 1914 four companies were operating glass sand quarries in Huntingdon county, namely:—the Pennsylvania Glass Sand Company, the Pittsburgh White Sand Company, the Juniata White Sand Company, and the Hummel Sand Company. Of these the Pennsylvania Glass Sand Company is the largest producer. This Company operates three plants at Mapleton, known as the Mapleton Works, the Keystone Works, and the Columbia Works, respectively. The Pittsburgh White Sand Company has two plants south of Mapleton, and the Juniata White Sand Company one, situated along the Juniata River in the town itself. The Hummel Sand Company was erecting a plant at Hummel Station on the Huntingdon and Broad-Top Mountain railroad, 18 miles south of Huntingdon, in 1914.

Mapleton Works of the Pennsylvania Glass Sand Company.

The Mapleton Works of the Pennsylvania Glass Sand Company are located just south of the town of Mapleton, on the east side of Sand Ridge. The plant which is connected with the main line of the Pennsylvania railroad by a siding, is located at the quarry.

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Sand Ridge rises to an elevation of about 120 feet above the level of Scrub Run at the north End of the quarry and 165 feet at the south end. The valley of this creek separates Sand Ridge from Jacks Mountain at this place. The floor of the quarry is about 50 feet above the level of the run. The Oriskany sandstone has a thickness of 168 feet and dips 53° to the northwest. At about the middle of the formation is a fossileferous bed of conglomerate, with quartz pebbles up to one-quarter inch in diameter. This conglomerate ranges in thickness from three feet at the north end to one foot at the southern end of the quarry. Quartz pebbles are also present occasionally at other horizons in the sandstone.

The sandstone has been badly fractured. Along the joint planes thus formed moderate amounts of iron in the form of limonite have been deposited from iron bearing solutions. Where the fracturing is especially intense in some cases the limonite has penetrated the rock itself. Portions of the rock also show occasional rust spots, dut to the weathering of some iron bearing mineral present in the rock. Occasionally a little black oxide of manganese has also been deposited as dendritic growths along some of the fracture planes. Outside of this the rock is nearly pure white quartz sandstone. It has undergone considerable disintegration through weathering, so that most of it crumbles readily into sand between the fingers. There are portions, however, which have escaped this weathering process and are still white to buff colored quartzites. Where these are encountered in considerable masses in the quarry they are left behind, the softer rock around them being removed.

The sandstone has been quarried for a distance of 1200 feet along the strike. At present both ends of the quarry are being worked, the highest portion of the north face rising about 70 feet above the floor of the quarry and the south face 115 feet. The rock is blasted down, advantage being taken of the fracture planes, and loaded into cars which are hauled to the plant by mules.

The Mapleton Works is equipped with two jaw crushers, and two six foot chaser mills to crush the stone into sand. Washing is done in screw washers of the type already described in a previous chapter of this report. For drying the sand, steam dryers are employed. The flow sheet of this plant is given on Plate LXXIII. The machinery is operated by electric power. Figure 1, Plate LXXIV, shows the external appearance of the works, while Figure 2, Plate LIX shows at the left in the foreground, the northern end of the quarry and at the right the plant for treating the stone. Most of the output is sold as No. 2 sand, although No. 1 sand can also be produced by sorting the rock in the quarry and using only the portions lowest in iron content for this grade.

Sand Rock from Quarry.

2-inch Grizzly — Oversize — Undersize   2-inch Grizzly — Oversize — Undersize

Jaw Crusher   Jaw Crusher

6' Lewistown Chaser Mill   6' Lewistown Chaser Mill.

6-mesh Revolving Screen   6-mesh Revolving Screen,
12- "   "   "   12 "   "   "

3 Screw Washers   3 Screw Washers,   2 Screw Washers   2 Screw Washers,

Screw Conveyor

2 Distributing Belt Conveyors,

Drainage Floor,
Shoveled by Hand
Bucket Elevator

2 Section Steam Drier,
Belt Conveyor
Bucket Elevator

18-mesh Revolving Screen

Storage Bin.

PLATE LXXIII.

Flow sheet of Mapleton Works of the Pennsylvania Glass Sand Company, Mapleton, Pa.

PLATE LXXIV.

Fig. 1.   Mapleton Works of Pennsylvania Glass Sand Company, Mapleton, Penna.

Fig. 2.   Keystone Works of Pennsylvania Glass Sand Company, Mapleton, Pa.
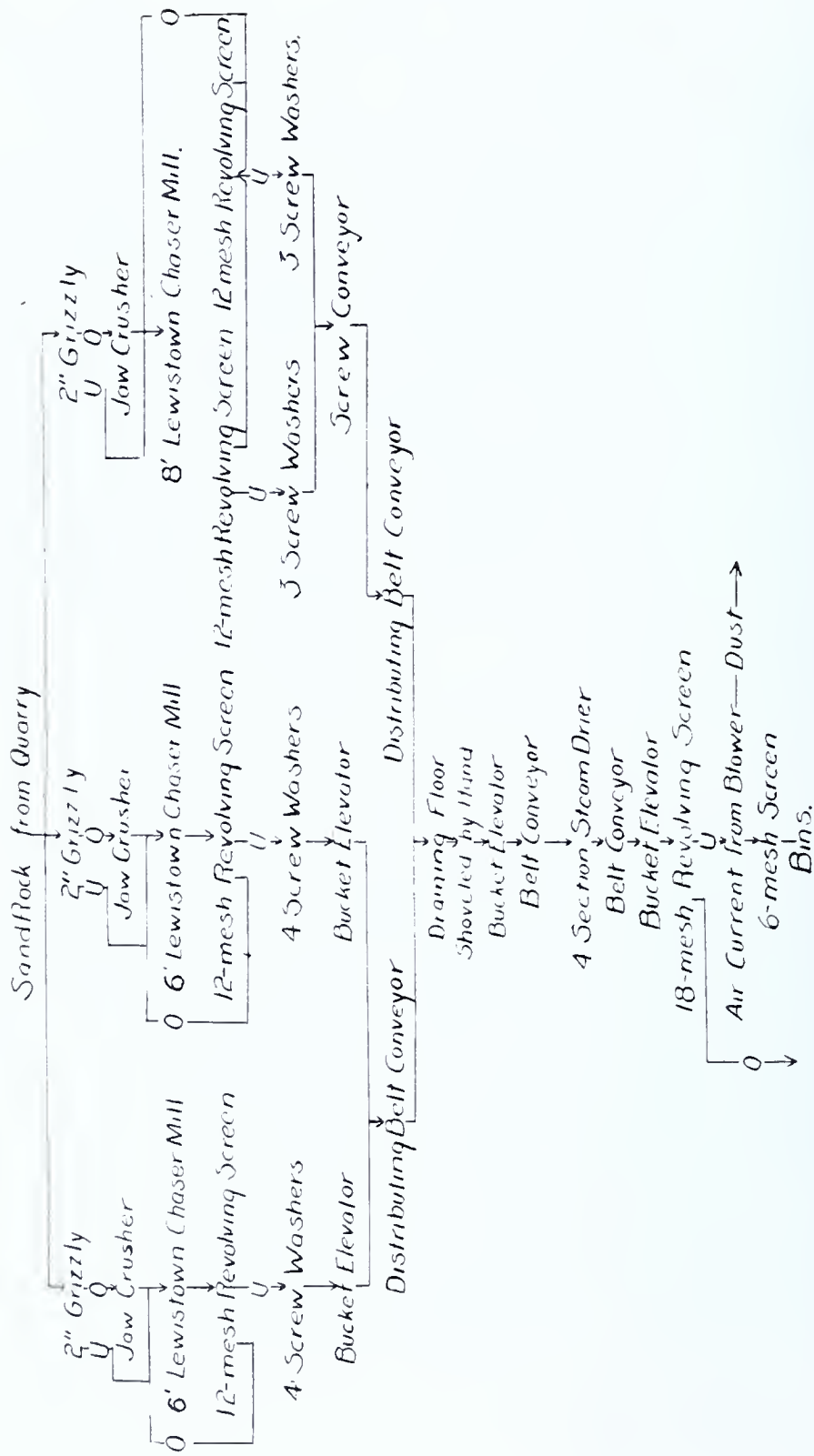
PLATE LXXV.

Flow sheet of the Keystone Works of Pennsylvania Glass Sand Company.

Keystone Works of the Pennsylvania Glass Sand Company.

The Keystone Works of the Pennsylvania Glass Sand Company are located about one mile north of Mapleton, on the east side of the Juniata River and on the west side of Sand Ridge, which in this vicinity rises as a steep escarpment to about 240 feet above the level of the valley. Plate LXVIII shows the appearance of the ridge at this place as seen from the west with the two quarries of the Keystone works at the right. Figure 2, Plate LXXIV is a nearer view of the plant with the North Quarry as a background. It is connected with the main line of the Pennsylvania railroad by a siding, which runs along the east side of the Juniata River at the foot of Sand Ridge.

The Oriskany sandstone in the vicinity of the Keystone Works has a thickness of about 130 feet. At the South Quarry the upper 80 feet of the formation have been quarried for a distance of 300 feet along the strike, while at the North Quarry, which is 300 feet to the northeast along the ridge, it has been quarried for a distance of 690 feet. The rock at both places is of excellent quality, being pure white in color and only moderately hard. Very little iron stain occurs along the joint planes. The following analysis of a sample of the sandstone from this vicinity shows its chemical composition:

Analysis of Sandstone from Keystone Works, Mapleton.

SiO_2,	99.76
Al_2O_3,	.14
Fe_2O_3,	.07
MgO,	none
CaO,	.28
H_2O,	.09
TiO_2,	.02
	100.36

In one place in the North Quarry the footwall has been broken through, thereby allowing a large amount of the underlying shale to be washed into the quarry. This has caused considerable inconvenience. At the south end of the quarry a streak of cream colored sand was encountered near the footwall. The quarries are both worked in two directions and it will, therefore, not be long before they meet. Plate LXIX, shows the appearance of a portion of the northeast working face of the North quarry at the time of the writer's visit in 1914. The rock is blasted down and loaded into cars which are hauled to the plant by mules.

At the plant the stone is crushed to sand by passing it through jaw crushers and chaser mills. Screw washers are used for washing the sand. After it has been allowed to drain for about 12 hours the washed sand is passed through a steam dryer before it is given a final screening. Plate LXXV gives a flow sheet of the mill, showing the treatment the sand receives from the time it reaches the plant

until it is ready to be loaded on cars. There are two six foot and one eight foot chaser mills. With the type of sandstone encountered in the two quarries these are capable of turning out 300 tons of sand per day of ten hours. About 1000 gallons of water, obtained from the Juniata River, are used per minute. The two six foot mills are run by steam, while electric power is employed to operate the eight foot mill.

The greater portion of the output is No. 1 sand for glass manufacture. The following two analyses show its composition:

Analyses of No. 1 Sand from Keystone Works.

	1.	2.
SiO_2,	99.36	99.70
Al_2O_3,	.17	.24
Fe_2O_3,	.06	.026
MgO,	none	traee
CaO,	.28	traee
H_2O,	.13	------
TiO_2,	.02	------
	100.02	99.966

No. 1 analysis by Charles R. Fettke.
No. 2 analysis by Booth, Garrett and Blair of Philadelphia.

The size of the grains is shown by the following screen analysis:

Through 14 mesh remaining on 20 mesh (.0328 inches diameter),	.07
Through 20 mesh remaining on 28 mesh (.0232 inches diameter),	1.59
Through 28 mesh remaining on 35 mesh (.0164 inches diameter),	13.11
Through 35 mesh remaining on 48 mesh (.0116 inches diameter),	61.71
Through 48 mesh remaining on 65 mesh (.0082 inches diameter),	20.35
Through 65 mesh remaining on 100 mesh (.0058 inches diameter),	2.79
Through 100 mesh remaining on 150 mesh (.0041 inches diameter),	.16
Through 150 mesh remaining on 200 mesh (.0029 inches diameter),	.03
Through 200,	.01
	99.72

Figure 1, Plate LXXVI shows the angular shape of the grains of this sand. The amounts of numbers 2 and 3 sand produced at the Keystone Works is relatively small on account of the excellent quality of the sandstone encountered in the quarries which supply this plant. The sand is divided into different grades on the basis of its iron content, the division being made in the quarry by roughly sorting the rock into different classes according to the amount of iron stain or limonite which it shows.

Columbia Works of the Pennsylvania Glass Sand Company.

The Columbia Works of the Pennsylvania Glass Sand Company is situated about three-fourths of a mile northwest of the Keystone Works, on the same side of Sand Ridge. They are also connected with the main line of the Pennsylvania railroad by a siding. Two quarries supply this plant with sandstone.

The South Quarry is located on the north side of a small creek which has cut a gap in Sand Ridge at this place. The Oriskany formation here has a thickness of about 200 feet and dips 62° to the
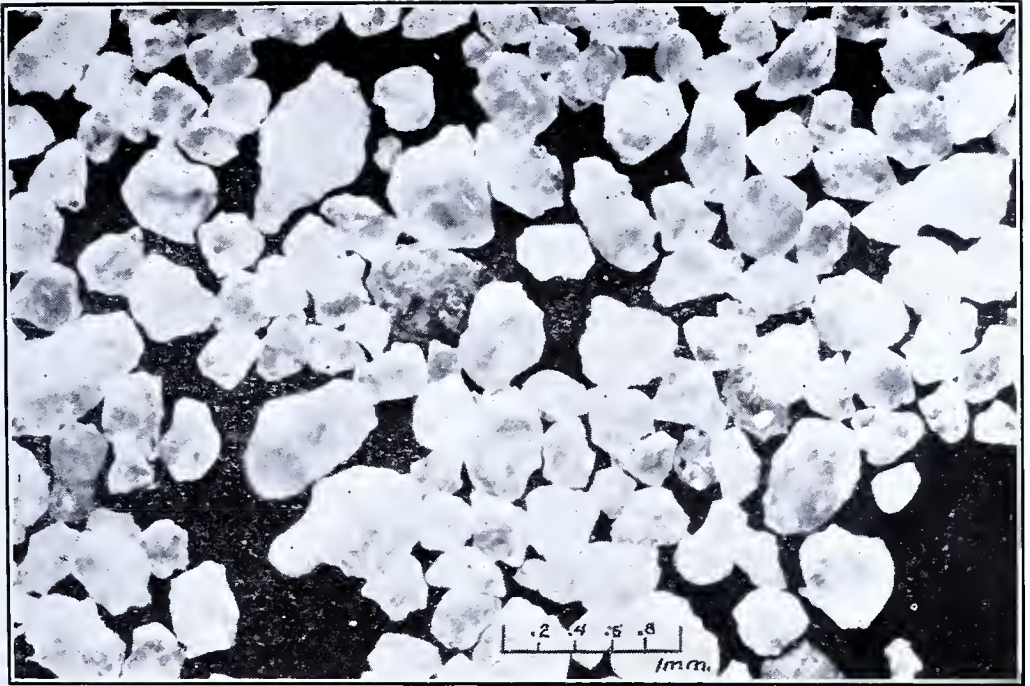
PLATE LXXVI.

Fig. 1.   Keystone No. 1 sand as it appears under the miscroscope.

Fig. 2.   Working face at North Quarry of the Columbia Works of Pennsylvania Glass Sand Company, Mapleton, Penna.

Sand Rock from Quarry

2" Grizzly — Jaw Crusher — 8' Lewistown Chaser Mill — 12-mesh Revolving Screen

O

4 Screw Washers
Screw Conveyor
Belt Conveyor
Draining Floor

Shoveled by Hand
Bucket Elevator
Belt Conveyor
Steam Drier
Belt Conveyor
Bucket Elevator
18-mesh Revolving Screen.

O Air Current from Blower—Dust →
6-mesh Screen
Bins.

2" Grizzly — Jaw Crusher — 8' Lewistown Chaser Mill — 12-mesh Revolving Screen

O

4 Screw Washers
Screw Conveyor
Belt Conveyor
Draining Floor

Shoveled by Hand
Bucket Elevator
Belt Conveyor
Steam Drier
Belt Conveyor
Bucket Elevator
18-mesh Revolving Screen

O

← Dust Air Current from Blower
mesh Screen
Bins.

PLATE LXXVII.

Flow sheet of Columbia Works of Pennsylvania Glass Sand Company, Mapleton, Pa.

PLATE LXXVIII.

Fig. 1. View in North Quarry of Pittsburgh White Sand Company, looking
northeast, Mapleton, Penna.

Fig. 2. View of quarry of Hummel Sand Company, at Hummel Station, Penna.

northwest. The top of the ridge rises 110 feet above the floor of the quarry. Figure 1, Plate LXX shows a view looking northeast towards the present working face. The sandstone is also pure white in color, but is somewhat harder than that encountered in the Keystone Quarries. Most of it cannot be crushed to sand between the fingers. It is badly fractured, as the illustration referred to above shows. Recently another quarry has been opened up about 700 feet to the northeast along the ridge. At the time of the writer's visit only the upper portion of the formation had been exposed. This is also pure white in color and is more friable than that encountered in the South Quarry. Much of it can be readily crushed to sand be tween the fingers. Figure 2, Plate LXXVI shows a portion of the working face of this quarry as it appeared in 1914.

At both quarries the sandstone is blasted down and loaded into cars which are hauled to the plant by mules. Here it is passed through jaw crushers and chaser mills. The resulting sand is then washed and dried in steam dryers. Plate LXXVII, gives the flow sheet at this plant, which is divided into two separate and independent units, each of which is provided with an eight foot chaser mill. The machinery is operated by steam power. Water for the chaser mills and screw washers is pumped from the Juniata River.

The output of the Columbia Works consists largely of No. 1 sand. The following analysis made by Booth, Garrett and Blair of Philadelphia, shows its composition:

Analysis of Sand from the Columbia Works.

SiO_2,	99.72
Al_2O_3,	.25
Fe_2O_3,	.014
MgO,	trace
CaO,	trace
	99.984

Pittsburgh White Sand Company.

The two plants of the Pittsburgh White Sand Company are located about two-thirds of a mile southwest of Mapleton, on the west or Hares Valley side of Sand Ridge. They are connected with the main line of the Pennsylvania railroad by a spur up the east side of Hares Valley. Two quarries are operated to supply these plants with sandstone.

The North, or oldest quarry, is situated at the sand washeries. On the northeast this quarry adjoins the Mapleton quarry of the Pennsylvania Glass Sand Company. The two properties overlap one another here for a short distance, the boundary line running along the top of the ridge. The quarry has been opened for a distance of about 2000 feet along Sand Ridge. Figure 1, Plate LXXVIII, shows a view of it taken from the southern end looking northeast. The

ridge rises to a maximum elevation of 160 feet above the bottom of the quarry. At the southwest end there is a bench 450 feet long, rising 95 feet above the present floor of the quarry. This bench is being taken out at the present time. Plate LVI shows a portion of the working face at this end of the quarry.

The Oriskany has a thickness of approximately 130 feet and dips $65\frac{1}{2}°$ to the northwest in this quarry. There has been considerable fracturing, producing one set of joint practically parallel to the bedding plane, while another set has a strike of N 69° E and a dip of 65° to the northwest. A screen analysis of a series of samples taken across the sandstone gave the following results:

Screen Analysis of Sandstone from Pittsburgh White Sand Company's Quarry, Mapleton.

Passed through 4 mesh, remaining on 6 mesh (.131 in. diameter),		.42
Passed through 6 mesh, remaining on 8 mesh (.093 in. diameter),		.73
Passed through 8 mesh, remaining on 10 mesh (.065 in. diameter),		1.73
Passed through 10 mesh, remaining on 14 mesh (.046 in. diameter),		1.57
Passed through 14 mesh, remaining on 20 mesh (.0328 in. diameter),		2.42
Passed through 20 mesh, remaining on 28 mesh (.0232 in. diameter),		7.36
Passed through 28 mesh, remaining on 35 mesh (.0164 in. diameter),		18.90
Passed through 35 mesh, remaining on 48 mesh (.0116 in. diameter),		47.84
Passed through 48 mesh, remaining on 65 mesh (.0082 in. diameter),		14.71
Passed through 65 mesh, remaining on 100 mesh (.0058 in. diameter),		2.18
Passed through 100 mesh, remaining on 150 mesh (.0041 in. diameter),		.48
Passed through 150 mesh, remaining on 200 mesh (.0029 in. diameter),		.37
Passed through 200, --		.42
		99.13

The sandstone is blasted down, as at the other quarries, loaded into cars and hauled to the plant by mules. Only one working face on the lower bench, near the southwest end of the quarry, is maintained at present.

In the northeast corner of the quarry, where it adjoins the property of the Pennsylvania Glass Sand Company, the lower portion of the formation is somewhat harder and can only be disintegrated between the fingers with difficulty. It consists of white sandstone with occasional specks of limonite. A miscropic examination of the rock showed that these occasional yellowish brown specks in the sandstone are probably due to the weathering of scattered grains of hornblende in the rock.

About three-fourths of a mile to the south, and along the west side of Sand Ridge, the Pittsburgh White Sand Company is opening up another quarry. At the time of the writer's visit no very great thickness of sandstone had yet been opened up by the quarrying operations, which were still confined to the upper portions of the formation. The sandstone at this place is somewhat harder than that exposed in the other quarries along Sand Ridge south of Mapleton, it being only possible to crush small fragments of it between the fingers with difficulty. It is white in color, except where it has been stained by a little limonite along a plane of fracture. The broken rock from this

Sand Rock, from Quarry

2" Grizzly

Jaw Crusher

Lewistown Chaser Mill

12-mesh Revolving Screen

4 Screw Washers

12-mesh Revolving Screen

4 Screw Washers

Screw Conveyor

2" Grizzly

Jaw Crusher

Lewistown Chaser Mill.

12-mesh Revolving Screen

4 Screw Washers

12-mesh Revolving Screen

4 Screw Washers

Inclined Belt Conveyor

Distributing Belt Conveyor

Draining Floor

Shoveled by Hand

Bucket Elevator

Belt Conveyor

Cummer Dryer

Screw Conveyor

Bucket Elevator

16-mesh Revolving Screen

Bucket Elevator

Bins.

PLATE LXXIX.

Flow sheet of North Plant of Pittsburgh White Sand Company, Mapleton, Penna.

Sand Rock, from Quarry
2" Grizzly
U   O
Jaw Crusher
Lewistown Chaser Mill
12-mesh Revolving Screen   12-mesh Revolving Screen.
O   U   U   O
3 Screw Washers   3 Screw Washers.
Screw Conveyor.
Distributing Belt Conveyor
Draining Floor
Shoveled by Hand
Bucket Elevator
Belt Conveyor
Bucket Elevator
Brick Drying Stack
Screw Conveyor
Bucket Elevator
Sheet Iron Cooling Tower
Bucket Elevator
16-mesh Revolving Screen.
O   U
Bins

PLATE LXXX.

Flow sheet of South Plant of Pittsburgh White Sand Company, Mapleton, Penna.

quarry is hauled to the washeries by means of a small steam loco-
motive running on a track along the foot of Sand Ridge.

Two separate plants have been erected for preparing the sand for
market. The method employed is essentially the same as that of the
other plants in the Mapleton district. Plates LXXIX and LXXX
give the flow sheets of the two washeries. Direct heat dryers, burn-
ing coke, are used instead of steam dryers. Two different types
are employed, that at the lower plant being a Cummer dryer, 25 feet
long and 10 feet in diameter, and that at the upper works a brick
stack dryer. At the lower plant there are two chaser mills, while
at the upper one only one has been installed. The machinery at
both places is operated by steam power. Water for the chaser mills
and washers is obtained from Hares Valley creek. It is first pumped
to a tank on top of a hill west of the plant and is then allowed to
flow to the plant by gravity. Three grades of sand are produced by
roughly sorting the stone in the quarry. The following analysis of
a sample of No. 1 sand from the plant of the Pittsburgh White Sand
Company, made by the Chief Chemist of the Pittsburgh Plate Glass
Company, gives the chemical composition:

Analysis of No. 1 sand from plant of Pittsburgh White Sand Company.

SiO_2,	99.885
Al_2O_3,	.022
Fe_2O_3,	.047 Fe .033
MgO,	trace
CaO,	.020
Loss on ignition,	.020
	99.994

Juniata White Sand Company.

The plant of the Juniata White Sand Company is situated in the
town of Mapleton, on a short siding of the Pennsylvania railroad.
The quarry from which the sandstone is obtained is located about
one and one-fourth miles south of the town, on the west side of Sand
Ridge. It is connected with the plant by a narrow gauge track,
over which the sandstone is hauled by a small steam locomotive.

The quarry has been opened for a distance of 300 feet along the
strike. The sandstone has a thickness of about 150 feet and dips
63° to the northwest. The surface of the highest outcrops along
Sand Ridge at this place rise 160 feet above the level of the quarry.
The sandstone is white in color, except where it has been occasionally
stained brown for several inches on either side of a pronounced joint
plane, which allowed iron bearing solutions to filter in and precipi-
tate limonite between the quartz grains. Here and there portions of
the rock have scattered through the minute specks of limonite,
which are probably due to the weathering of occasional grains or horn-
blende, which a microscopic examination of the rock showed to be
present. Fracturing in the sandstone is pronounced. While the

hardest rock present can only be disintegrated into sand between the fingers with difficulty, most of it crumbles readily to white sand in the hand.

The plant for preparing the sand for market is equipped with one eight foot chaser mill. With the exception of a 35 foot brick stack dryer, burning coke, employed at this works for drying the sand, the treatment which the sand receives is practically the same as the standard practice of the Mapleton district. Plate LXXXI, gives the flow sheet for this sand works. The plant has a capacity of about 150 tons of sand per day of 10 hours and uses 600 gallons of water per minute, pumped from the Juniata river. The machinery is operated by electric power, although an auxiliary steam plant is also at hand in case the electricity should be cut off for any length of time. Three grades of sand are made by sorting the stone in the quarry. The following analysis made by Otto Wuth, of Pittsburgh, shows the chemical composition of a sample of No. 1 sand prepared at this plant:

Analysis of No. 1 Sand from Plant of Juniata White Sand Co.

SiO_2,	99.85
Al_2O_3,	.14
Fe_2O_3,	.012
MgO,	------
CaO,	trace
	100.002

Hummel Sand Company.

The plant and quarry of the Hummel Sand Company are situated on a siding of the Huntingdon and Broad-Top Mountain railroad, at Hummel Station, about 18 miles south of Huntingdon. A quarry is being opened on the south side of a gap which occurs in the low ridge formed by the Oriskany sandstone at this place. About 75 feet of sandstone are exposed, dipping 38° to the southeast. At the time of the writer's visit in 1914, exploratory work had not proceeded very far, so that the sandstone was nowhere exposed for more than ten feet below the surface. The lower portion of the formation as opened up at the time was the most disintegrated. Here considerable loose sand of a yellowish brown color was present with masses of readily crushed sandstone, usually stained somewhat by limonite, imbedded in it. The upper portion of the formation is firmer. Considerable fracturing has occurred and some discoloration by limonite along the joint planes thus developed has taken place. Much of this rock has a white color, although often when blocks of apparently white rock are broken into discoloration by limonite is found on the inside. The upper few feet of the formation have a very coarse texture. From the above description it is seen that the type of rock thus far opened up at this place will yield only a second class glass

Sand Rock from Quarry

12" X 20" Blake Jaw Crusher

Bucket Elevator

8' Lewistown Chaser Mill

12-mesh Revolving Screen   12-mesh Revolving Screen

O   U   U   O

5 Screw Washers   5 Screw Washers

Drag Washer.

Distributing Belt Conveyor

Draining Floor

Shoveled by Hand

Bucket Elevator

Belt Conveyor

Bucket Elevator

35' Brick Drying Stack

Screw Conveyor

Bucket Elevator

14-mesh Revolving Screen

O   U

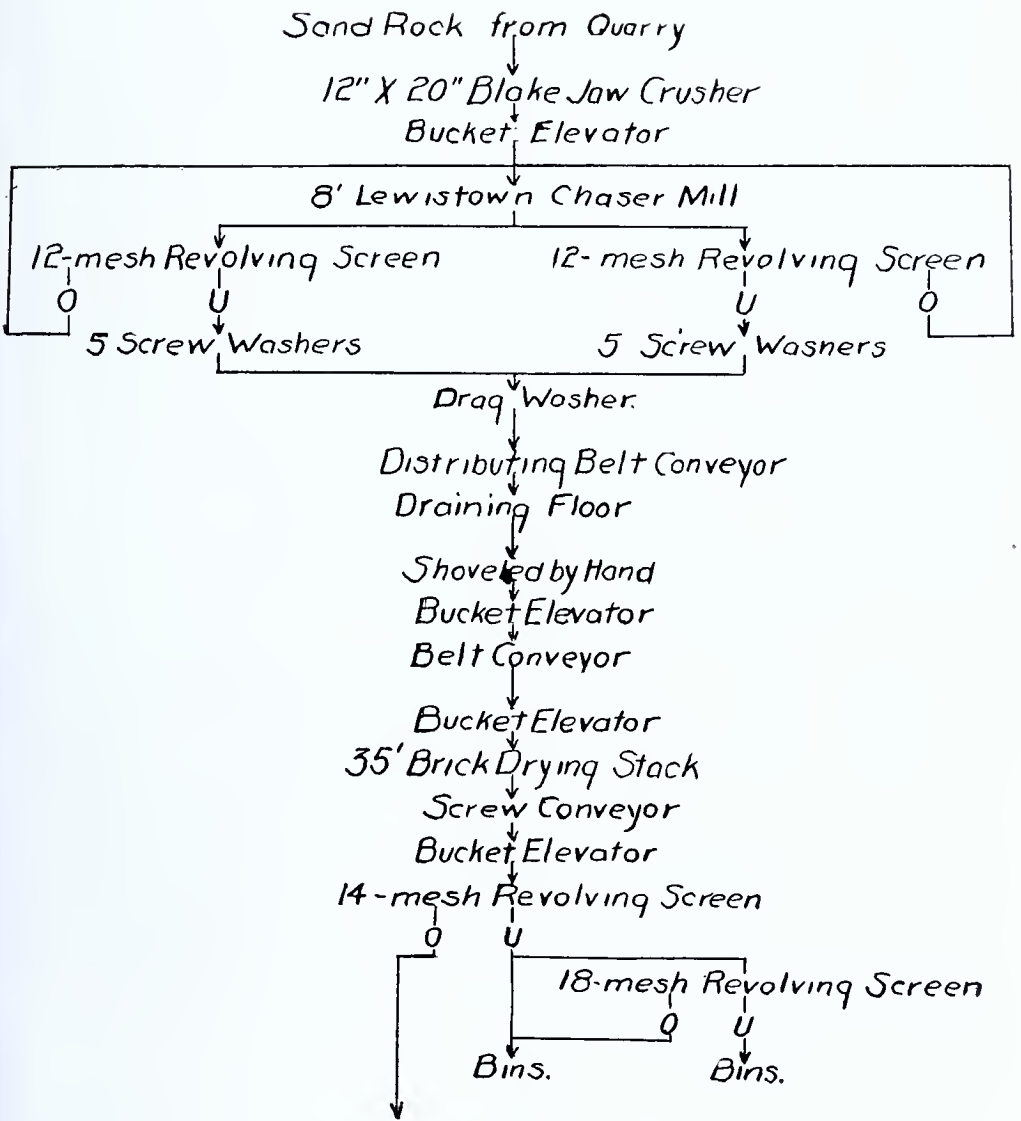18-mesh Revolving Screen

O   U

Bins.   Bins.

PLATE LXXXI.

Flow sheet of plant of Juniata White Sand Company, Mapleton, Penna.

sand on washing.   Figure 2, Plate LXXVIII shows the appearance of the quarry in the summer of 1914.

The plant itself is equipped with a 20x18 inch jaw crusher, a nine foot Phillips and McLaren wet grinding pan, with revolving screen, four screw washers, and the necessary belt conveyors to handle the sand.   A boiler and engine have been installed to run the machinery and a draining shed has been built.   There is no dryer at the plant at present, the intention of the owners being to produce only No. 2 sand and to ship it wet.   Later on, if considerable quantities of sandstone are encountered in the quarry that will yield No. 1, sand, a dryer may be built.   Water is brought through a six inch pipe from a point on a creek above the mill.   No sand had been shipped at the time of the writer's examination of the property.   An analysis of a sample of the sand which had been put through the grinding pan and screw machines, made by the writer, showed .11% Fe_2O_3.   This sand was cream colored in appearance.   A screen analysis showed the presence of the following sizes of grains:

Screen Analysis of Sand from Hummel White Sand Company Plant.

Passed through 10 mesh, remained on 14 mesh (.046 in. in diameter),	.59
Passed through 14 mesh, remained on 20 mesh (.0328 in. in diameter),	.51
Passed through 20 mesh, remained on 28 mesh (.0232 in. in diameter),	1.22
Passed through 28 mesh, remained on 35 mesh (.0164 in. in diameter),	3.92
Passed through 35 mesh, remained on 48 mesh (.0116 in. in diameter),	17.39
Passed through 48 mesh, remained on 65 mesh (.0082 in. in diameter),	46.91
Passed through 65 mesh, remained on 100 mesh (.0058 in. in diameter),	26.98
Passed through 100 mesh, remained on 150 mesh (.0041 in. in diameter),	1.86
Passed through 150 mesh, remained on 200 mesh (.0029 in. in diameter),	.24
Passed through 200 mesh, ---	.15

99.77

Undeveloped Areas.

The most promising sites for the opening of new glass sand quarries in Huntingdon County occur along Sand Ridge.   The portion of the ridge southwest of the South Quarry of the Pittsburgh White Glass Sand Company undoubtedly contains large quantities of sandstone suitable for first class glass sand, as does that portion north of the Saddler Run Gap, northeast of Mill Creek.   Along the former portion of the ridge are about 10 miles of outcrop while along the latter portion about five miles which warrant investigation by companies that are looking for deposits of high grade glass sand.   The former portion is somewhat more accessible as far as transportation facilities are concerned, than the latter.   Of course careful prospecting and some development work should be done at any site selected before a plant is erected, as in many cases it is impossible to determine from a mere inspection of the outcrop whether the sandstone underneath is suitable or not, especially when there is a considerable cover of soil.

Abundant deposits of somewhat inferior grades of sand also occur along Warriors Ridge at places where at present they are only made use of in small quantities for local use as building or furnace sand. Where only a second grade glass sand is desired these deposits are available. Similar deposits occur at several places along the Oriskany outcrop on the western side of Black Log Mountain, especially in the vicinity of Orbisonia, but these are not as conveniently situated with respect to transportation facilities as are the Warriors Ridge deposits.

JACKS MOUNTAIN.

Oriskany Sandstone.
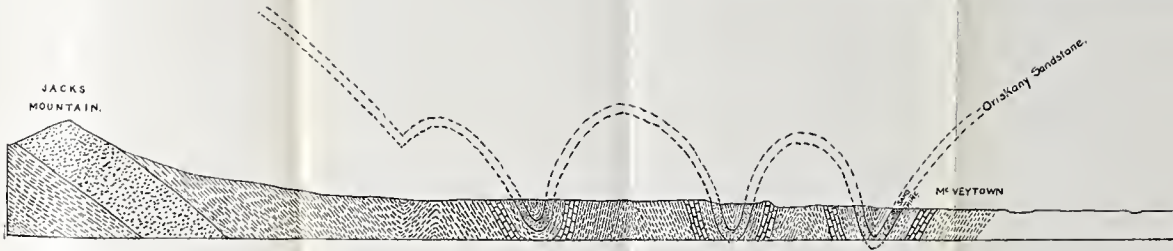
MⁱVEYTOWN

Modified after Ashburner, 2nd Geol. Surv. of Pa.

2000 feet.

PLATE LXXXII.
Geologic Cross-section of Mifflin County, in the vicinity of McVeytown.

CHAPTER XVII.

GLASS SAND DEPOSITS OF MIFFLIN COUNTY.

Location of Outcrops.

Mifflin County, which adjoins Huntingdon County on the northeast, has had the same geological history that the latter has passed through. It is underlain by the same formations and the gologic structure is similar. The youngest beds of which any remnants have been left by erosion belong to the upper Devonian, while the oldest strata exposed are of Ordovcian age. The Tuscarora sandstone is also the ridge making rock of the region. Its outcrop forms Standing Stone Mountain along the northwestern boundary of the county, Jacks Mountain along the center, and Blue Ridge along the southeastern boundary. Between Standing Stone and Jacks Mountains there is an anticline while between Jacks Mountain and Blue Ridge a syncline occurs.

A comparatively small remnant of the Oriskany, which at one time covered this entire area, has been preserved from erosion in the syncline between Jacks Mountain and Blue Ridge. A number of minor flexures occur along the axis of this syncline, which runs across Mifflin county in a northeast-southwest direction. As a result the outcrop of the Oriskany formation forms a number of roughly parallel bands which cross the central portion of Mifflin County from the northeast to the southwest boundary, as shown on the map of Huntingdon, Mifflin and Bedford counties given in Plate LXV, which has the outcrops of the Oriskany sandstone indicated on it. Plate LXXXII shows a section at right angles to the strike of the formations in the vicinity of McVeytown. Three of the minor synclinal flexures present here in the broad syncline of southeastern Mifflin county contain remnants of the Oriskany sandstone, which have been preserved from erosion. Much of the Oriskany sandstone of Mifflin county is still a hard white quartzite, which is fairly resistant to erosion, so that it often forms minor ridges in central Mifflin County. Under certain favorable conditions, however, it has been thoroughly disintegrated by circulating water to a friable sandstone, and in places even to a loose sand.

Workable Portions.

Portions of the Oriskany sandstone suitable for glass sand occur in the vicinity of Burnham, north of Lewistown; near Granville, southwest of Lewistown; at McVeytown, and in the district around Vineyard.

The syncline northeast of Burnham contains a narrow belt of Oriskany sandstone, together with a little overlying Devonian shale, preserved from erosion along its axis. It pitches toward the northeast so that this strip of overlying Devonian shale gradually becomes wider and wider as the Oriskany along the axis becomes buried deeper and deeper toward the northeast. A low ridge is formed by the northwest or steep limb of this syncline northeast of Burnham. The southeast limb has a gentle dip, as a rule, and crops out along the east side of this ridge. Usually it is covered by soil which has been washed over it from higher up the slope. At Burnham, Kishickoquillas Creek has cut a valley through it where it crosses at right angles. All of the Oriskany has been removed at this gap, the valley being deeper than the former level of the Oriskany along the axis of the syncline at this place. Northeast of Burnham, along this ridge, Oriskany outcrops are encountered, which in places have weathered to loose sand.

The first opening is that on the property of John Miller, situated about one and three-fourths miles northeast of Burnham. The southeast limb of the syncline which crops out on the southeast slope of the ridge at this place has a very gentle dip to the northwest. Mr. Miller has driven a tunnel into the hill, approximately 700 feet long, to cut the sandstone at a level of about 100 feet below its outcrop. The sandstone of this limb of the syncline has been disintegrated to loose sand by the agents of weathering. As exposed in the caved openings along the outcrop above the mine workings, it is seen to be a light, yellowish brown in color and appears as though it ought to yield a No. 2 sand on washing. An analysis made by the writer of a sample obtained at this place gave .18% Fe_2O_3. The following screen analysis gives the percentage of the different sized grains present in this sand:

Passed through 14 mesh, remained on 20 mesh (.0328 inches),	_____	.02%
Passed through 20 mesh, remained on 28 mesh (.0232 inches),	_____	.21%
Passed through 28 mesh, remained on 35 mesh (.0164 inches),	_____	1.13%
Passed through 35 mesh, remained on 48 mesh (.0116 inches),	_____	10.48%
Passed through 48 mesh, remained on 65 mesh (.0082 inches),	_____	56.76%
Passed through 65 mesh, remained on 100 mesh (.0058 inches),	_____	25.43%
Passed through 100 mesh, remained on 150 mesh (.0041 inches),	_____	2.64%
Passed through 150 mesh, remained on 200 mesh (.0029 inches),	_____	1.30%
Passed through 200 mesh,	_____	1.58%

99.55

The outcrop of the northwest limb of the syncline at this place occurs along the top of the ridge. It is marked by a prominent projecting ledge of fairly hard sandstone and a large number of detached boulders. The boulders and outcropping ledges are mostly angular, only a little rounding of the corners having occurred. This indicates that the rock underneath is fairly hard. The rock of the ledges and boulders is also spotted more or less by limonite which renders it unfit for a first class glass sand. Figure 1, Plate LXXXIII, shows a
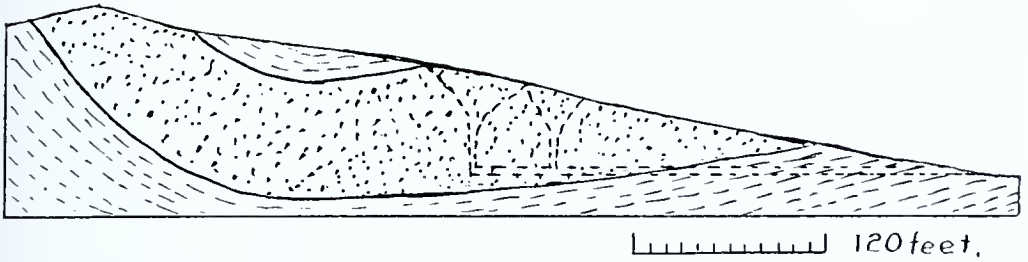
PLATE LXXXIII.

Fig. 1. Cross section of ridge northeast of Burnham, at John Millers Sand
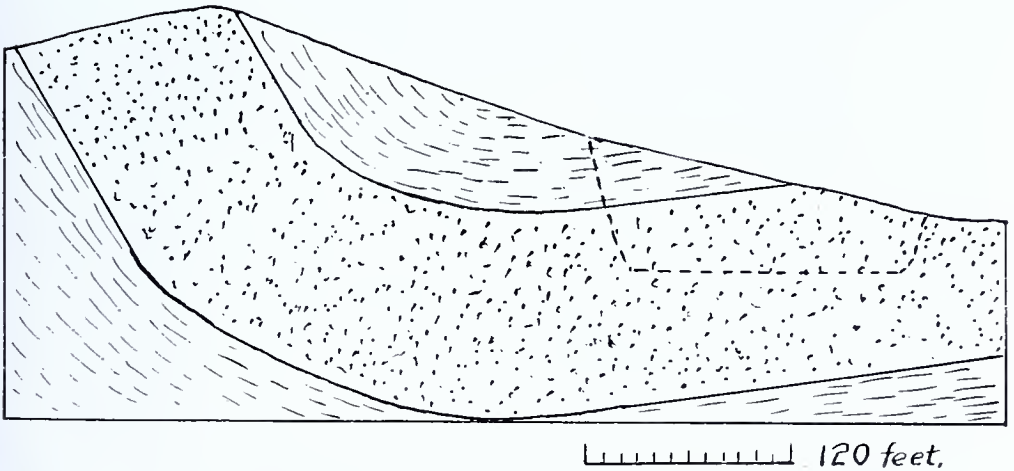Mine, showing position of Oriskany sandstone.

Fig. 2.   Similar section at sand pit of Standard Steel Company.
(See figure 3 on other sheet of illustrations.)

PLATE LXXXIII.

Fig. 3.   View in sand pit of Standard Steel Company,
northeast of Burnham.

cross section of the ridge at this place, indicating the probable struct-
ure of the Oriskany sandstone underneath.

About one-quarter mile northeast of John Miller's sand mine, along
the same ridge, is a large pit from which the Standard Steel Company,
of Burnham, is obtaining furnace sand. This pit is also on the south-
east limb of the syncline where it crops out well down on the side of
the hill. Figure 2, Plate LXXXIII, shows a cross section of this syn-
cline and the position of the sand pit in the Oriskany formation,
while figure 3 shows a view of the pit. A thickness of 35 feet of
sandstone is exposed in the pit, dipping 8° to the northwest. Of
this the upper 15 feet are pretty badly stained by limonite, but the
lower 20 feet, especially in the southwest face, which is 200 feet long,
are of excellent quality. The sandstone has been completely disinte-
grated to pure white sand with only a very slight staining from iron
oxide along joint planes. A test pit at this place showed that the
white sand extends at least 10 feet deeper than the present floor of
the pit. This material will yield an excellent quality of glass sand
provided foreign material from overlying strata is not allowed to be-
come mixed with it. Along the northwest face there are at present
45 feet of shale and soil in addition to the 15 feet of sand stained with
limonite. If glass sand were to be produced here this overlying ma-
terial would have to be stripped or else the sand would have to be
won by underground mining.

Along the top of the ridge above the Standard Steel Company's pit
the ledges and boulders which mark the outcrop of the northwest limb
of the syncline are well rounded, indicating that the underlyiing
rock has probably undergone considerable disintegration. Here and
there the surface of the ridge is also strewn with white sand washed
out by the rain. This is usually a sign that there is a comparatively
friable sandstone underneath. The outcrop material is compara-
tively free from limonite.

About 900 feet northeast of the Standard Steel Company's pit is
another sand pit on the same limb of the syncline. This has a maxi-
mum depth of 30 feet and a breadth of 25 feet at the bottom. It is
240 feet long. The sandstone at this place has also been disinte-
grated to loose sand, which has a light, yellowish brown color. The
upper portions near the surface contain considerable amounts of
limonite in the form of irregular hard masses along seams in the sand.
This sand would not make a first class sand even on washing. About
one-half mile further to the northeast, along the ridge, where a road
crosses it, a small pit about five feet deep with one to two feet of
soil cover has been opened in loose Oriskany sand on what is appar-
ently the north west limb of the syncline. This end also has a light,
yellowish brown color.

Friable sandstone and loose sand also occur in the middle syncline between Lewistown and Burnham, on the southwest side of Kishickoquillas valley. Some sand has been taken out on the southwest side of the road, up a small valley, which has been cut across the Oriskany outcrop at this place. Most of the rock is exceedingly friable and breaks up readily into a light, yellowish brown sand. Portions of the formation are very fossiliferous. On the northeast side of this same valley a quarry has been opened on the northwest limb of the syncline. The floor of the quarry is a little above the level of the creek and the working face is about 55 feet high. Northeast of the quarry the ridge formed by the Oriskany outcrop is about 110 feet wide. Most of the sandstone disintegrates readily into sand. Considerable iron in solution has filtered in along joint planes and has been deposited in the sand on either side as limonte, as a result the sand derived from it is not white and careful sorting in the quarry would have to be resorted to to make even a No. 2 grade of glass sand.

About 700 feet northeast of the above quarry a pit has been opened in an open field in the loose sand occurring along the Oriskany outcrop. It is about 120 feet long, 50 feet wide, and 20 feet deep, with about 3 feet of surface soil. This pit is also on the northwest limb of the syncline. The sand does not contain as much limonite as that from the quarry described above, being lighter in color.

Another sand bank to supply the local demand for building and other sand has been opened in the southwestern part of the town of Lewistown, on the southeast limb of the easternmost of the three synclinal flexures between Burnham and Lewistown, where a small creek has cut a valley across the formation south of Kishickoquillas creek. This sand bank is situated on the northeast side of this valley. The formation here dips 40° to the northwest. Its upper portion is very fossiliferous and is stained with considerable limonite. It crumbles qute readily into sand. The lower porton on the other hand contains very few fossils and is much lighter in color. Portions of it are almost pure white. The hill at this place rises about 120 feet above the floor of the lower opening. About 25 feet below the top is another opening. In it the upper 20 feet are also very fossiliferous and are pretty badly discolored by limonite, while the lower 25 feet consists of fairly friable sandstone which crumbles readily into sand. Here and there, however, some limonite occurs in it along seams running in various directions. A fault, nearly parallel to the strike, separates the upper and lower portions of the formation, which is, therefore, undoubtedly over 45 feet thick at this place.

About three and three-fourths miles southwest of Lewistown, in the vicinity of Granville, along the same limb of the easternmost of the synclines containing Oriskany sandstone, the sandstone has also been

disintegrated by weathering into loose, and at this place, pure white sand. It is being mined by the Pennsylvania Glass Sand Company. Figure 1, Plate LVIII, shows a cross section of the syncline at this place. The southeastern limb, which has a thickness of 100 feet, dips $42\frac{1}{2}°$ to the northwest. It has been intersected by a cross cut tunnel at a depth of about 200 feet below the outcrop. Nearly all of the sandstone down to this level has been disintegrated by circulating water to a practically white sand, and indications are that this disintegration has extended to still greater depths, perhaps even as far as the bottom of the synclinal trough. A sample of this loose white sand taken from one of the chutes in the mine showed on analysis the presence of .11% Fe_2O_3. Along the top of the ridge which is formed by the northwestern limb of this syncline the rock consists of a comparatively hard white quartzite.

Following southwestward, along the belt of Oriskany outcrops, excellent deposits of glass sand are again encountered in the vicinity of McVeytown. These are also developed on the southeast limb of the easternmost of the three synclinal flexures containing Oriskany sandstone, which are present northwest of McVeytown. This sand has been mined for a distance of nearly 4300 feet along the strike, southwest from the gap northeast of McVeytown. Two mines were formerly situated along this outcrop, one at the gap northeast of McVeytown, known as the Dull mine, and the other 1700 feet to the southwest along the outcrop, known as the Macklin mine. Both were owned by the Pennsylvania Glass Sand Company at the time they were shut down.

The lower workings in the Dull mine are down 180 feet below the present level of the water in the pit at the shaft, which is about 35 feet above the level of the Juniata river. The outcrop of sandstone, dipping 62° to the northwest, on which these mines are located also occurs on the side of a ridge on top of which the northwestern limb of the syncline crops out as a comparatively hard white quartzite, dipping 73° to the southeast. According to J. H. Dewees[53] the Oriskany sandstone at the Dull mine has a thickness of about 140 feet, of which the lower portion is yellow and the upper layers are bluish gray and yellow white, the middle 100 feet are almost pure white sand of excellent quality for the manufacture of glass. Mr. W. P. Stevenson, of McVeytown, informed the writer that the formation yielded a very pure white sand for a width of 110 feet in the Dull mine. Figure 2, Plate LVIII, shows a section of the ridge on which these outcrops occur at the abandoned Macklin works of the Pennsylvania Glass Sand Company. It shows the hard quartzite limb of the syncline cropping out near the top of the ridge, while the friable disintegrated limb, in which the mines were opened, crops out at the

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53. Second Geological Survey of Pennsylvania, Report F, 1878, p. 92.

surface along its southeastern side, pretty well down toward the foot of the slope. Practically all of the sandstone of this limb crumbles readily into white sand in the hand, much of it being already loose sand as it occurs in place.

As has already been stated loose white sand was encountered in the Dull and Macklin mines for a distance of over 4300 feet, southwest along the strike of the Oriskany formation from the gap northeast of McVeytown, where the Dull works of the Pennsylvania Glass Sand Company were formerly situated. This same bed continues northeast along the southeast slope of the ridge for a distance of several miles, but as yet has not been explored to any extent except by shallow pits. It is very likely that sand of good quality will also be encountered when this portion of the formation is exploited.

The other outcrops of the Oriskany to the northwest, as exposed along the valley which forms the gap northeast of McVeytown, were also examined. The rock at these places was found for the greater part to consist of hard white quartzite. A similar examination was made of the outcrops in the gap of about three miles northeast of McVeytown. Here only two synclines containing Oriskany sandstone are present. The southeast limb of the easternmost of these is covered, while the northwest limb forms the first ridge northwest of the Juniata Valley. A light brown sand occurs in a cut along the road which follows the northeast side of the valley forming the gap through the ridge at this place. To the northeast the ridge rises 230 feet above the level of the valley. There are no prominent ledges cropping out along it, but more or less rounded boulders of Oriskany sandstone are scattered over its surface. When broken into, they are seen to have a light, yellowish brown color and are moderately hard, although pieces of the rock can be crumbled into sand between the fingers. Considerable quantities of white sand have also been washed out along the ridge. On the whole, surface indications are such as to warrant further exploration here for possible bodies of rock suitable for glass sand. The other outcrops examined along the northwest-southeast valley, which connects Juniata with Ferguson Valley, did not look very promising for glass sand.

About two miles southwest of McVeytown the road to Mount Union crosses the southwest limb of the syncline on which the Dull and Macklin mines are located. The outcrop is quite low at this place but to the southwest, beyond the creek which crosses it, it rises again as a rather prominent ridge. At the road the sandstone has become disintegrated into a light yellow sand. To the southwest the disintegration has not gone quite so far, but the rock can still for the most part be readily crushed into sand between the fingers. Where traced for a distance of about one and one-half miles the appearance of the outcrop is such as to indicate that the Oriskany sandstone along it

PLATE LXXXIV.

Fig. 1.   Near view of Oriskany sandstone in Hatfield Quarry of Pennsylvania
Glass Sand Company, at Vineyard.

Fig. 2.   Hatfield Works of Pennsylvania Glass Sand Company, Vineyard, Pa.

may be suitable for glass sand.   Only very small amounts of limonite
are present in the outcrop rock.   Following northwest, along the
creek referred to above, several more synclines containing Oriskany
are crossed, but some of these outcrops have a very favorable appear-
ance as possible sources of glass sand.

Continuing further to the southwest portions of the Oriskany sand-
stone suitable for glass sand are again encountered in the vicinity
of Vineyard.   The first deposit is that of the Hatfield works of the
Pennsylvania Glass Sand Company, about one mile northeast of Vine-
yard.   This quarry is located on a portion of the Oriskany sandstone
which forms the cap rock of a synclinal ridge.   Since the sandstone
at this place occurs along the axis of the syncline it is badly fractured
as is shown in Figure 1, Plate LXXXIV.   The Juniata River swings
in a broad curve against the ridge at this place and has cut back
beyond the axis of the syncline so as to expose the formation, as
shown in Figure 2, Plate LXXXIV.   The rock at the extreme left
of the picture, covered largely by vegetation, is limestone dipping to-
ward the right, while that in the railroad cut to the extreme right is
also limestone dipping toward the left.   The Oriskany sandstone
above the limestone is shown in the quarry back of the Hatfield works
at the center of the picture.   The ridge, with the sandstone outcrop
along its crest, can be followed for about 1500 feet northeast from
the Hatfield quarry.   Beyond, the sandstone disappears, having been
removed by erosion along the axis of the syncline, which rises higher
and higher in a northeast direction.   At the quarry, the crest of the
ridge is about 300 feet above the floor of the quarry.   The present
working face reaches within about 100 feet of the top and is about
150 feet wide at the base, with a slope of $36\frac{1}{2}°$.

Reference has already been made to the fact that the sandstone at
the Hatfield quarry is badly fractured.   This has allowed ground
water to circulate freely throughout it and has resulted in the thor-
ough disintegration of the rock, so that most of it crumbles readily to
a loose sand and can be washed down from the face of the quarry
by turning a stream of water under pressure against it.   Some rem-
nants of less disintegrated sandstone, however, are also present be-
tween the fracture planes.   The sand along the joint planes is dis-
colored somewhat by limonite, while the less disintegrated sandstone
masses as a rule are white in color and are very little stained by iron
oxides.   An average sample of the loose sand from the quarry showed
.17% Fe_2O_3 to be present on analysis.

At Vineyard the Pennsylvania Glass Sand Company operates an-
other quarry known as the Enterprise.   This is situated on the ridge
northwest of Vineyard on the northwest limb of the syncline on whose
axis the Hatfield quarry is located.   The formation has been quar-
ried here for a distance of about 650 feet along the strike to a maxi-

num depth of 125 feet below the surface of the outcrop. At the north-east end the quarry has a width of 180 feet at the surface and at the southwest end 240 feet. The dip at the middle is about 20° to the southeast. This increases toward the northeast. The sandstone is badly fractured and disintegration along joint planes has been pronounced. Unfortunately the loose sand thus formed has been stained with limonite to such an extent that it is only available for No. 2 glass sand. The masses of less disintegrated rock as a rule are white and comparatively free from iron so that they yield a No. 1 sand. The outcrop is on the side of a gentle sloping hill underlain by shale and limestone. The sandstone forms a low ridge on the side of this hill and dips away from it. Drainage down the hill is toward the sandstone outcrop. Conditions are, therefore, favorable for an abundant supply of surface water getting across to the sandstone which explains the thorough disintegration of the latter at this quarry.

About one mile southwest of the Enterprise quarry, along the same limb of the syncline, the Crystal Sand Company has opened a quarry. The sandstone at this place is almost horizontal and is much less disintegrated than at the Enterprise quarry. It can only be crushed into sand with difficulty between the fingers. Considerable fracturing has occurred in the rock and some limonite has been deposited along practically every joint plane thus developed, but it does not penetrate the rock itself to any extent. The rock itself is white in color. The quarry has been opened for a length of about 600 feet along the strike and is 300 feet wide. The working face at the west end is 40 feet high and at the east end 20 feet. The upper 8 feet of sand are badly discolored by limonite. These 8 feet, together with 2 feet of soil, have to be stripped before the underlying rock can be removed.

Continuing southwest along the outcrop the rock gradually becomes more and more of the nature of a quartzite. About one-fourth mile south of the Crystal Sand Company's quarry the Juniata Silica Company at one time operated a sand plant, which was dismantled and abandoned a number of years ago. The Oriskany sandstone at this place is also very nearly horizontal. It is harder than the sandstone encountered at the Crystal Sand Companys quarry. The amount of fracturing is about the same. Limonite has been deposited along joint planes in small amounts, but does not penetrate the rock itself. Ten feet of stripping, consisting mostly of well disintegrated but badly iron stained Oriskany sandstone, were necessary before quarrying operations could be conducted. Both underground mining and open quarry methods of obtaining the sandstone were employed. This is the last place in southwestern Mifflin county at which any attempt has been made to obtain glass sand from the Oriskany sandstone.

History of the Glass Sand Industry in Mifflin County.

In 1868 openings were first made along the Oriskany outcrop in Granville township, three miles southwest of Lewistown, by Bumgardner & Franklin, of Lancaster, Pennsylvania, who were prospecting for glass sand. A deposit of high grade silica sand was discovered and mining operations were, therefore, commenced. A small plant was erected with a daily capacity of forty tons of prepared sand, which was hauled to Lewistown for shipment. In 1875 a cable transmission line to Granville station on the Pennsylvania railroad was erected and the sand was conveyed in buckets a distance of one and three-fourths mile to the shipping point. At the same time the output was increased to 60 tons per day.

After the Pennsylvania Canal along the Juniata Valley was abandoned, a siding from the Pennsylvania railroad was laid down on the tow-path which brought shipping facilities closer to the mines. A large storage and drying plant were erected and the aerial tramway was dismantled. The sand was conveyed by means of a pipe line from the crushing mill to the drying and storage building and the capacity of the plant was increased to daily output of 75 tons.

About this time the firm of Bumgardner & Franklin was dissolved and the Juniata Sand Company was incorporated in its place. The stockholders were Lancaster investors, George M. Franklin of the old firm being the principal stockholder and president of the company. In 1899 the output of the mine was handled by the Pennsylvania Glass Sand Company, a Delaware corporation, which also controlled the output of all the glass sand producing plants in the Juniata Valley.

In 1902 the Juniata Sand Company sold the plant to the Pennsylvania Glass Sand Company, which corporation also purchased all the plants whose output was at this time handled by the Pennsylvania Glass Sand Company, of Delaware, mentioned above. The new owners enlarged the plant and increased the output to two hundred tons daily capacity.

In 1869 Wirt & Davis operated a primitive plant at McVeytown, washing the sand in boxes, with a daily capacity of ten tons. The enterprise was a failure and in 1870 they ceased operations. B. A. Bradly and C. P. Dull formed a partnership under the name of Bradly & Dull and took over the property. They erected a small mill with more modern methods than their predecessors used, and increased the daily output to forty tons. The sand was hauled a distance of a mile across the Juniata River to McVeytown station on the Pennsylvania railroad. At this time the average capacity of a railroad car was

twelve tons.   First class glass sand sold in Pittsburgh market for $12.00 a ton and the freight rate from McVeytown was $3.75 per ton.

B. A. Bradly died in 1890 and the business was continued by C. P. Dull, the daily capacity of the plant having been increased to 75 tons. In 1897, Dull installed a pump and pumped the sand through a four inch pipe line to a drying and storage building at the railroads, at the same time considerably increasing the output.   In 1902 Dull sold to the Pennsylvania Glass Sand Company.

In 1885 Charles Miller opened a sand deposit on the lands of D. M. Dull near McVeytown.   Only a small amount of sand was mined and the methods used were primitive.   In a short time he was succeeded by Dull, Wilson & Gray.   The partnership had existed only a short time when Gray withdrew and the business was continued by Dull and Wilson.   In 1890 they ceased operations and Macklin and Stevenson succeeded them and operated the plant until 1902 when they sold to the Pennsylvania Glass Sand Company, which company operated the Dull, and the Macklin and Stevenson plants along with the Granville mine until 1912, when the two plants at McVeytown were abandoned.

In 1878 David S. Forgy and Samuel Witherow made an opening at Vineyard station, seven miles west of McVeytown.   They continued operations until 1881 when the partnership was dissolved and William Ewing, James Macklin and W. P. Stevenson took a lease on the sand property, operating it under the name of the Enterprise Sand Company.   1882 the property was purchased from D. S. Forgy by Macklin & Stevenson who continued to operate it until 1902 when the business was sold to the Pennsylvania Glass Sand Company, which has operated the plant since its purchase by it.

In 1886 an opening was made on the property of James and Joseph Forgy, one mile southwest of Vineyard by John S. Bare & Company.   Works were erected and operated.   This plant was operated during the year following under various names, among them Bare & Walton, and Walton & Fleming, and was finally in 1896 merged into the Crystal Sand Company, of which the largest stockholders are the former partners.   These works are still in operation.

In 1892 an opening was made a short distance southwest of the Crystal Sand Company's plant.   After some prospecting, quite a large sand crusher and flint mill was erected.   The parties interested were from Wellsville, Ohio, the manager being W. S. Stevenson.   The business was not successful and after some years of operation under the name of Juniata Silica Company, the works were closed, dismantled and the property sold.

In 1912 the Pennsylvania Glass Sand Company erected a large crushing and grinding plant between Ryde and Vineyard station, six miles southwest of McVeytown. The buildings are of brick, concrete, and steel. This plant has a capacity of 600 tons of washed sand and a drying capacity of 400 tons. Power is electric and steam. The sand is largely mined by the hydraulic system. The harder rock encountered is put through a jaw crusher and chaser mill.

While there have been quite a large number of other sand properties opened up beside those mentioned, they have all been abandoned on account of an inferior quality of sand, or on account of poor location with respect to shipping facilities. For the above account of the glass sand industry of Mifflin county the writer is indebted to Mr. W. P. Stevenson of McVeytown.

Description of Glass Sand Quarries and Plants at Present in Operation

Durng the summer of 1914 there were two companies producing glass sand in Mifflin county and one operator who was installing the machinery necessary to wash sand for the glass industry. The two companies referred to are the Pennsylvania Glass Sand Company and the Crystal Sand Company. John Miller, of Lewistown, was installing equipment to prepare some glass sand for his mine northeast of Burnham. The Pennsylvania Glass Sand Company operates three plants in Mifflin county, namely, one at Granville known as the Juniata Works, and two at Vineyard known as the Hatfield and Enterprise Works respectively. The Crystal Sand Company has one plant at Vineyard.

Juniata Works of the Pennsylvania Glass Sand Company.

The Juniata Works of the Pennsylvania Glass Sand Company is located on the west bank of the Juniata River about three and three-fourths miles southwest of Lewistown. It is connected with the main line of the Pennsylvania railroad by a spur which joins the former near the station of Granville. The mine which supplies this plant with sand is located about 2700 feet northwest of the plant, in a synclinal ridge which rises about 500 feet above the level of the river and trends in a northeast and southwest direction.

Figure 1, Plate LVIII, shows a cross section of the ridge and the position of the Oriskany outcrop on it. As has already been stated in a previous paragraph the northwest limb which crops out at the top of the ridge has undergone very little change and is still a white hard quartzite. The southeast limb on the other hand has undergone considerable disintegration, so that it now consists entirely of loose white sand and very friable sandstone. An analysis of this sand showed .11% Fe_2O_3. A screen analysis showed that it is made up of the following sized grains:

Passed through a 10 mesh sieve, caught on a 14 mesh (.046 inches),		.01
Passed through a 14 mesh sieve, caught on a 20 mesh (.0328 inches),		.28
Passed through a 20 mesh sieve, caught on a 28 mesh (.0232 inches),		1.31
Passed through a 28 mesh sieve, caught on a 35 mesh (.0164 inches),		5.15
Passed through a 35 mesh sieve, caught on a 48 mesh (.0116 inches),		20.77
Passed through a 48 mesh sieve, caught on a 65 mesh (.0082 inches),		36.80
Passed through a 65 mesh sieve, caught on a 100 mesh (.0058 inches),		24.32
Passed through a 100 mesh sieve, caught on a 150 mesh (.0041 inches),		5.14
Passed through a 150 mesh sieve, caught on a 200 mesh (.0029 inches),		2.91
Passed through a 200 mesh sieve, ---		2.23
		99.97

The formation is 100 feet thick at the mine and dips $42\frac{1}{2}°$ to the northwest.

The present tunnel, which is about 140 feet above the level of the river and 1200 feet long, cuts the sandstone at a depth of about 220 feet below the surface. From this tunnel a gang way has been run in the sandstone along the hanging wall for a distance of 1100 feet to the northeast and 1500 feet to the southwest. Forty feet above the gangway a drift has been run parallel to it and also next to the hanging wall, with chutes every 200 to 300 feet to connect it with the former. Plate LXXXV, shows the method of mining employed to obtain the sand. An old tunnel which cut the sandstone 90 feet above the level of the present main gangway was employed to mine the sandstone above that level, so that there are about 40 feet of sandstone between the present upper drift and the abandoned workings above.

The main gangway is 8 feet wide at the bottom, $5\frac{1}{2}$ feet at the top, and 6 feet high. The upper drift is 7 feet wide at the bottom, $4\frac{1}{2}$ feet at the top and 6 feet high. Rooms are driven from the upper level across the formation to the footwall every 15 feet. These rooms are of the same width and height, when first driven, as the level itself. They are then gradually widened and increased in height from the footwall toward the hanging wall as shown in the illustration. The men stand on the loose sand and broken sandstone in the rooms to drill and shoot down the rock overhead. From one-half to two-thirds of the sand present is recovered. In the rooms the sand is loaded into cars which are trammed by hand to the chutes along the upper level. The sand from these chutes is then allowed to run into cars in the main gangway below and is hauled to the mouth of the tunnel by mules. From there it is hauled to the washing and drying plant by a small steam locomotive. A great deal of timber is required in the drifts and rooms. The sand is mostly loose and at times, when it is saturated with water, runs almost like quicksand. A great deal of difficulty was experienced when the lower tunnel was first driven on account of the water in the abandoned upper workings. This had to be drained off.

The sand as it comes from the quarry is already a loose white sand containing only a few lumps of friable sandstone which crumble readily to sand between the fingers. No crushing machinery is,

60 feet.
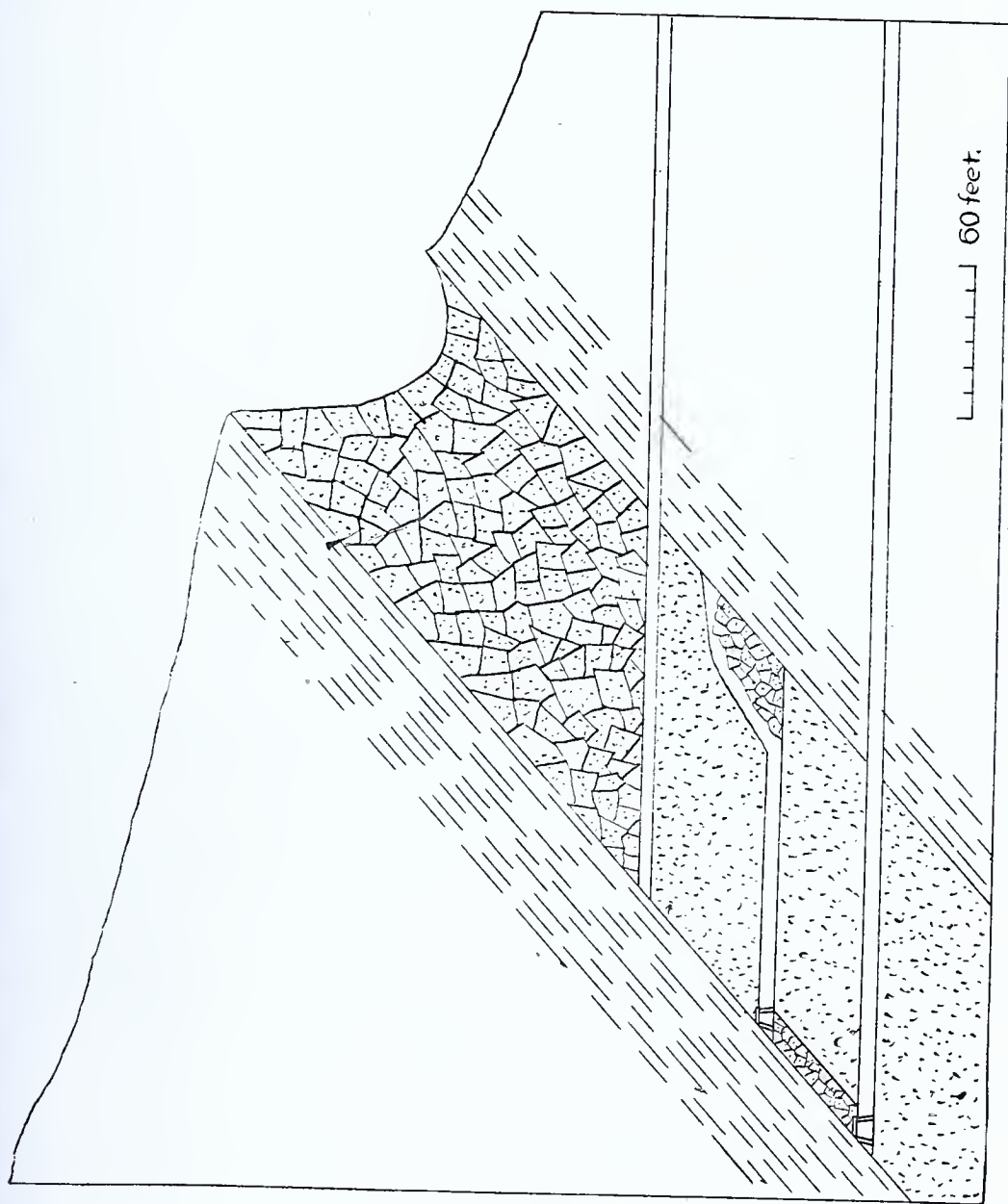
PLATE LXXXV.

Diagram showing method of mining sand employed at Juniata Mine of Pennsylvania Glass Sand Company, Granville, Pa.

Sand from Mine

1" diameter Plate Screen.

¼" diameter Plate Screen

12-mesh Revolving Screen

4 Screw Washers.

12-mesh Revolving Screen

4 Screw Washers

Screw Conveyor

Screw Conveyor Distributors.

Draining Floor

Shoveled by Hand

Horizontal Belt Conveyor

Inclined Belt Conveyor

Cummer Dryer

To Revolving Screens and Storage Bins

PLATE LXXXVI.

Flow sheet of Juniata Works of Pennsylvania Glass Sand Company, Granville, Pa.
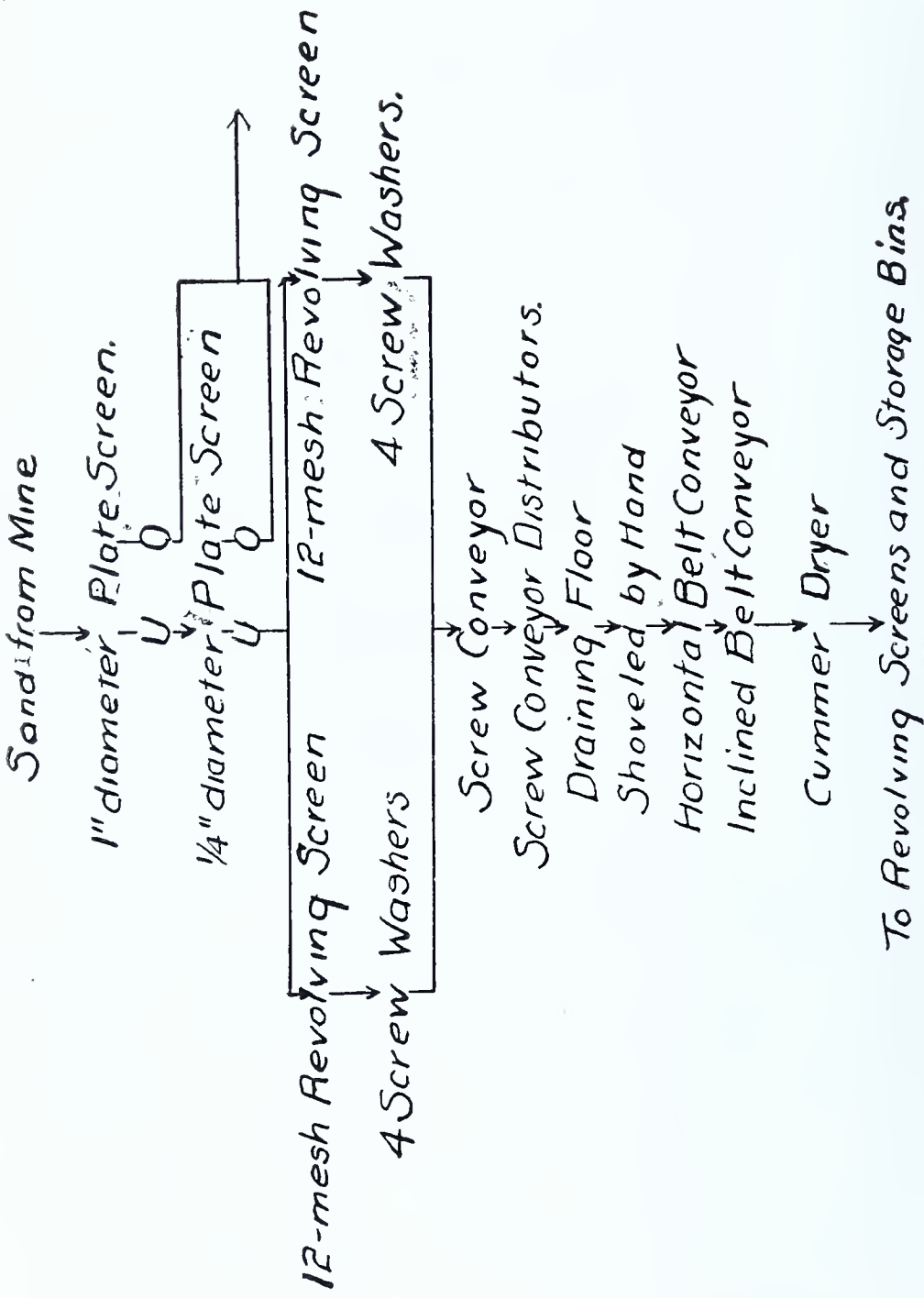
therefore, required at the Juniata Works, the sand being simply screened and then sent directly to the screw washers. A Cummer dryer is used to dry the sand. Plate LXXXVI shows the flow sheet of the mill. The washing plant has a capacity of 125 to 135 tons of sand per day of ten hours, while the Cummer Dryer has a capacity of 120 tons. A pulverizing mill is located at this plant in which part of the sand is pulverized in tube mills to a fine powder. The greater portion of the output of the Juniata Works of the Pennsylvania Glass Sand Company consists of an excellent grade of No. 1 glass sand, due to the fact that the sand as it comes from the mine consists of practically nothing but quartz grains and contains almost no iron oxides.

Hatfield Works of the Pennsylvania Glass Sand Company.

The Hatfield works of the Pennsylvania Glass Sand Company are situated along the west side of the Pennsylvania railroad about one mile northeast of Vineyard. This quarry is located on a portion of the Oriskany sandstone which is an erosion remnant preserved along the axis of a syncline. It forms at this place the cap rock of a synclinal ridge which rises about 350 feet above the level of the Juniata Valley, and can be followed for a distance of 1500 feet in a northeast direction from the quarry. The river in making a broad curve has cut back beyond the axis of the syncline thus exposing the sandstone in a favorable position for quarrying. Figure 2, Plate LXXXIV shows the plant and the quarry back of it.

The rock is badly fractured as is shown in Figure 1, Plate LXXXIV. Disintegration along the joints thus developed has been pronounced so that large quantities of loose sand are present and the sandstone between them is friable that it crumbles readily to sand between the fingers. The sand along the joint planes is, as a rule, discolored somewhat by limonite, but the writer was informed that No. 1 sand can be made from it by washing. The sandstone itself is usually white and shows very little iron stain. An analysis of a representative sample of the loose sand found in the quarry shows the presence of .17% Fe_2O_3. Another sample of sand which had been washed to the foot of the quarry contained .16% Fe_2O_3. An analysis of the No. 1 glass sand produced at the Hatfield works indicated the presence of .06% Fe_2O_3. Screen analysis of the loose sand from the quarry and the No. 1 sand gave the following results:

Passed through 10 mesh,	caught on 14,	.36	------
Passed through 14 mesh,	caught on 20,	1.26	.05
Passed through 20 mesh,	caught on 28,	3.04	1.23
Passed through 28 mesh,	caught on 35,	7.45	4.88
Passed through 35 mesh,	caught on 48,	35.32	34.80
Passed through 48 mesh,	caught on 65,	33.51	41.03
Passed through 65 mesh,	caught on 100,	11.09	15.04
Passed through 100 mesh,	caught on 150,	2.38	2.09
Passed through 150 mesh,	caught on 200,	1.55	.49
Passed through 200 mesh,		3 30	..16
		99.26	99.77

The present quarry face is about 150 feet wide at the base and 190 feet high with a slope of $36\frac{1}{2}°$. Most of the sand is sufficiently loose so that it can be washed down the face of the quarry into flumes which carry it to the mill, by turning a stream of water under pressure on it. The boulders of less disintegrated sandstone accumulate on the slope near the base, and from time to time are loaded into cars and are taken to the mill to be crushed. Occasionally a blast is set from holes drilled down from above, back of the quarry face, to loosen large quantities of rock.

At the Hatfield Works all of the No. 1 sand is put through a nine foot chaser mill before it is washed. Steam dryers are employed for drying. Plate LXXXVII shows the flow sheet of the mill. This is one of the most up to date and the largest sand plant at present operated in the State. It has a daily capacity of 600 tons of washed sand and a drying capacity of 400 tons. The building in which the mchinery is housed is of brick, concrete, and steel construction. The drainage room has a capacity of 4500 tons. At present the sand is shoveled by hand from the draining floor onto belt conveyors which carry it to the steam dryers, but the intention is eventually to install a traveling crane and scoop to accomplish this. The mill is equipped with radiators and steam pipes to prevent the wet sand from freezing in the chaser mill, screw washers, and on the belt conveyors during the winter months. Exhaust steam is used for this purpose. The machinery can be operated either by steam or electric power. The dry sand is conveyed through pipes underneath the hopper bottom bins into cars so that no hand labor is required in loading. A pulverizing mill is operated in connecton wth the plant.

Enterprise Works of the Pennsylvania Glass Sand Company.

The Enterprise Works of the Pennsylvania Glass Sand Company is located on a short siding at the station of Vineyard, on the Pennsylvania railroad. The quarry is situated a short distance to the northwest in a body of Oriskany sandstone dipping 20° to the southwest, which forms the northwest limb of a syncline at this place, and which is the southerly extension of the southwest pitching syncline on which the Hatfield Quarry is located.

The sandstone is badly fractured and disintegration along joint planes is pronounced. Unfortunately the loose sand thus formed has been stained with limonite to such an extent that it is only available for No. 2 glass sand. The masses of less disintegrated rock as a rule are white and comparatively free from iron, so that they yield a No. 1 sand. The sandstone outcrop forms a low ridge on the side of a gently sloping hill underlain by shale and limestone, which rises to the northwest of the Juniata Valley at Vineyard.

The sandstone is cut by a tunnel through the overlying shales at
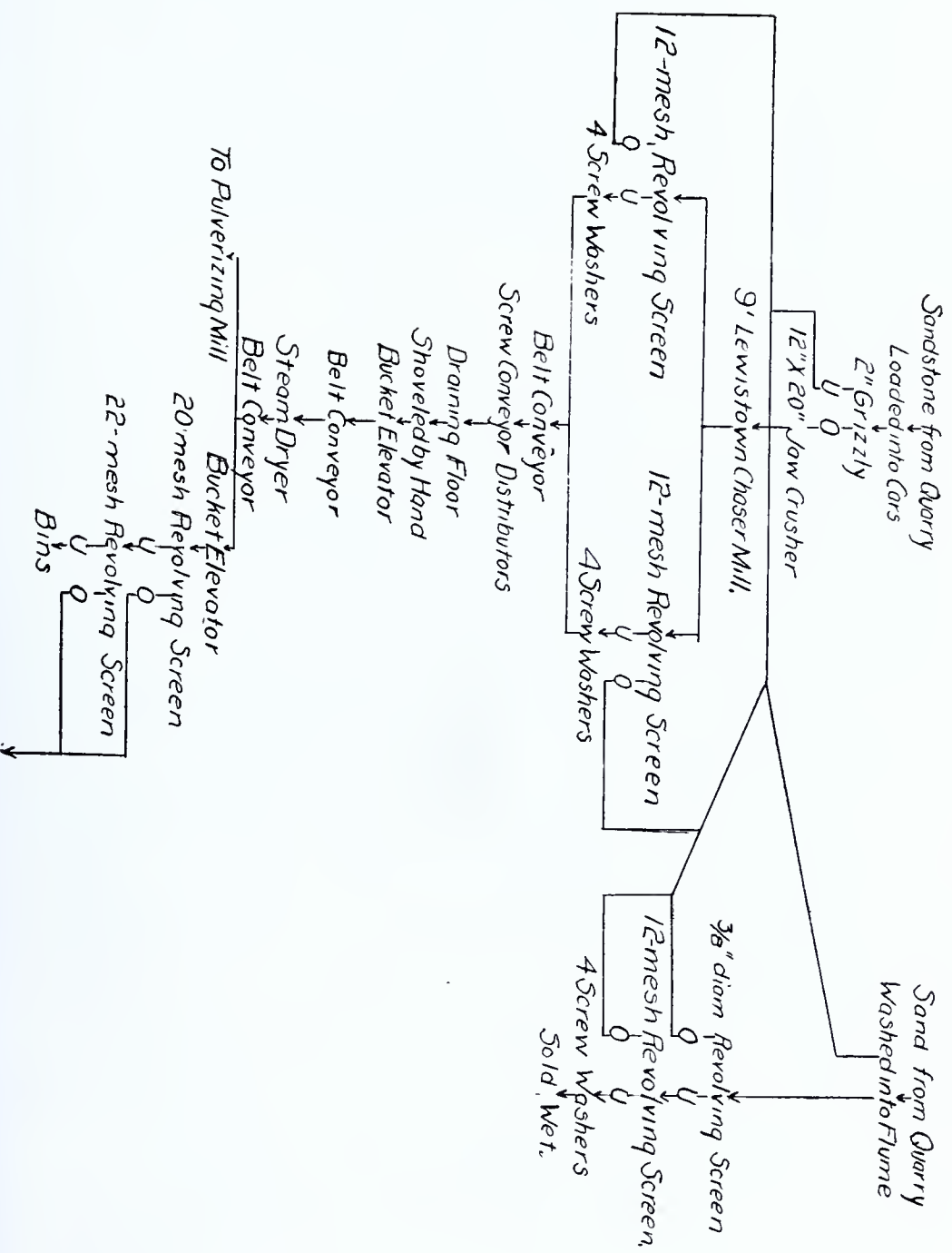
PLATE LXXXVII

Flow sheet of Hatfield works of the Pennsylvania Glass Sand Company at Vineyard, Pa.
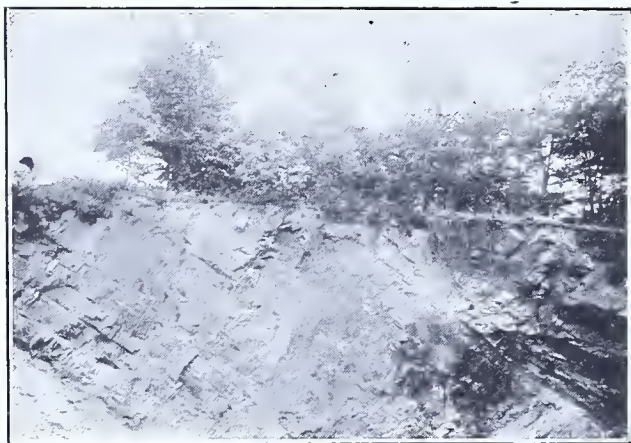
PLATE LXXXVIII

Fig. 1. View in Enterprise Quarry of Pennsylvania Glass Sand Company, looking northeast, Vineyard, Pa.

Fig. 2. View in central portion of above quarry.

Fig. 3. View looking southwest in above quarry.

PLATE LXXXIX.

Flow sheet of Enterprise Works of Pennsylvania Glass Sand Company, Vineyard, Pa.
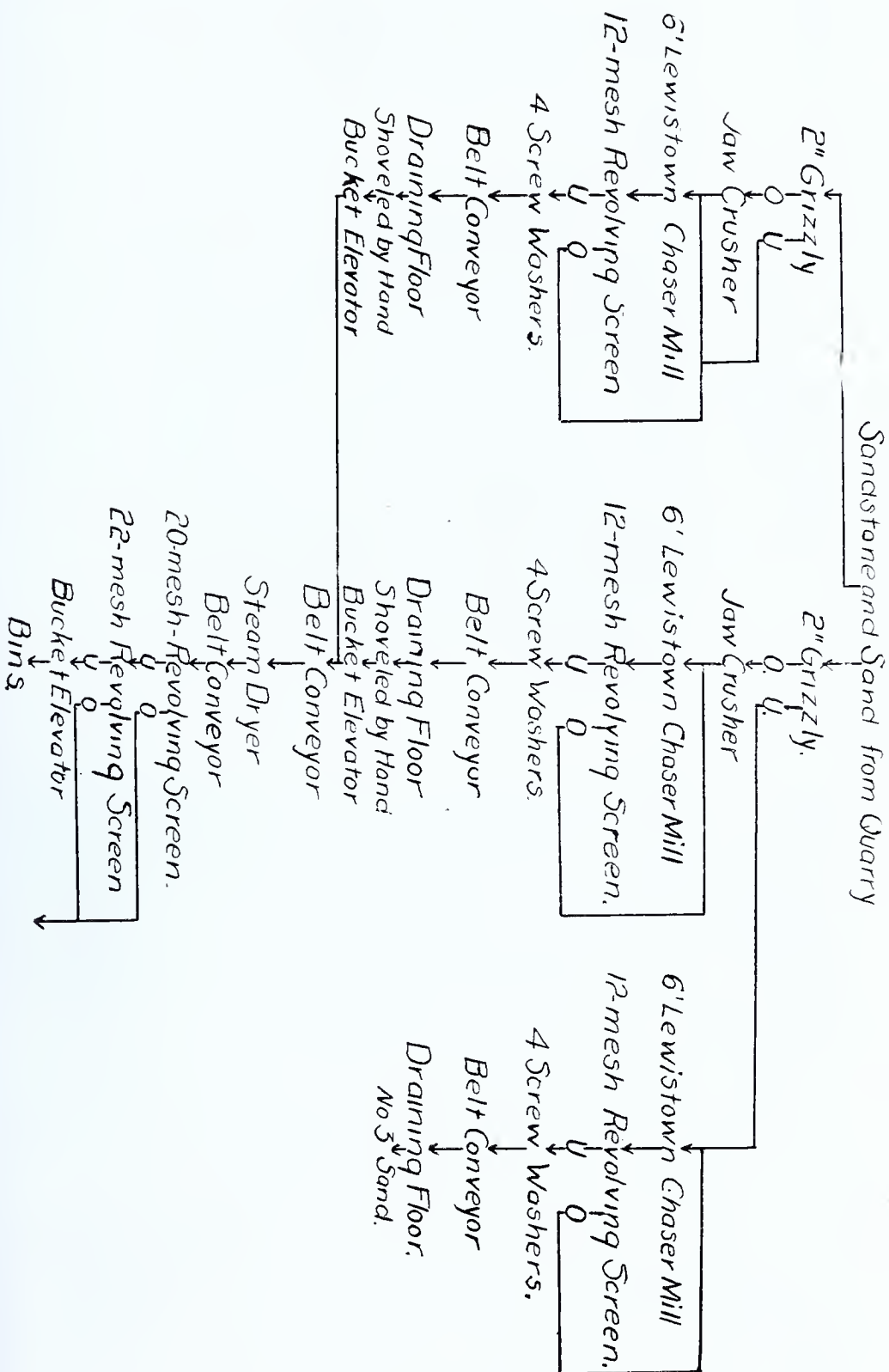
PLATE XC.

Fig. 1. View in quarry of Crystal Sand Company. Vineyard, Pa.

Fig. 2. View in quarry of Calvin Ritchey. Tatesville, looking north.

Sandstone from Quarry

2" Grizzly — Jaw Crusher — 6' Chaser Mill — 12-mesh Revolving Screen — 4 Screw Washers — 12-mesh Revolving Screen — 4 Screw Washers — Inclined Belt Conveyor

2" Grizzly — Jaw Crusher — 6' Chaser Mill — 12-mesh Revolving Screen — 4 Screw Washers — 12-mesh Revolving Screen. — 4 Screw Washers — Inclined Belt Conveyor

Horizontal Belt Conveyor — Draining Floor — Shoveled by Hand — Bucket Elevator — Horizontal Belt Conveyor — Bucket Elevator — Horizontal Belt Conveyor — Steam-Dryer — Horizontal Belt Conveyor — 16-mesh Revolving Screen — Bucket Elevator — Bins.

PLATE XCI.

Flow sheet of Crystal Sand Company's Plant, Vineyard, Pa.

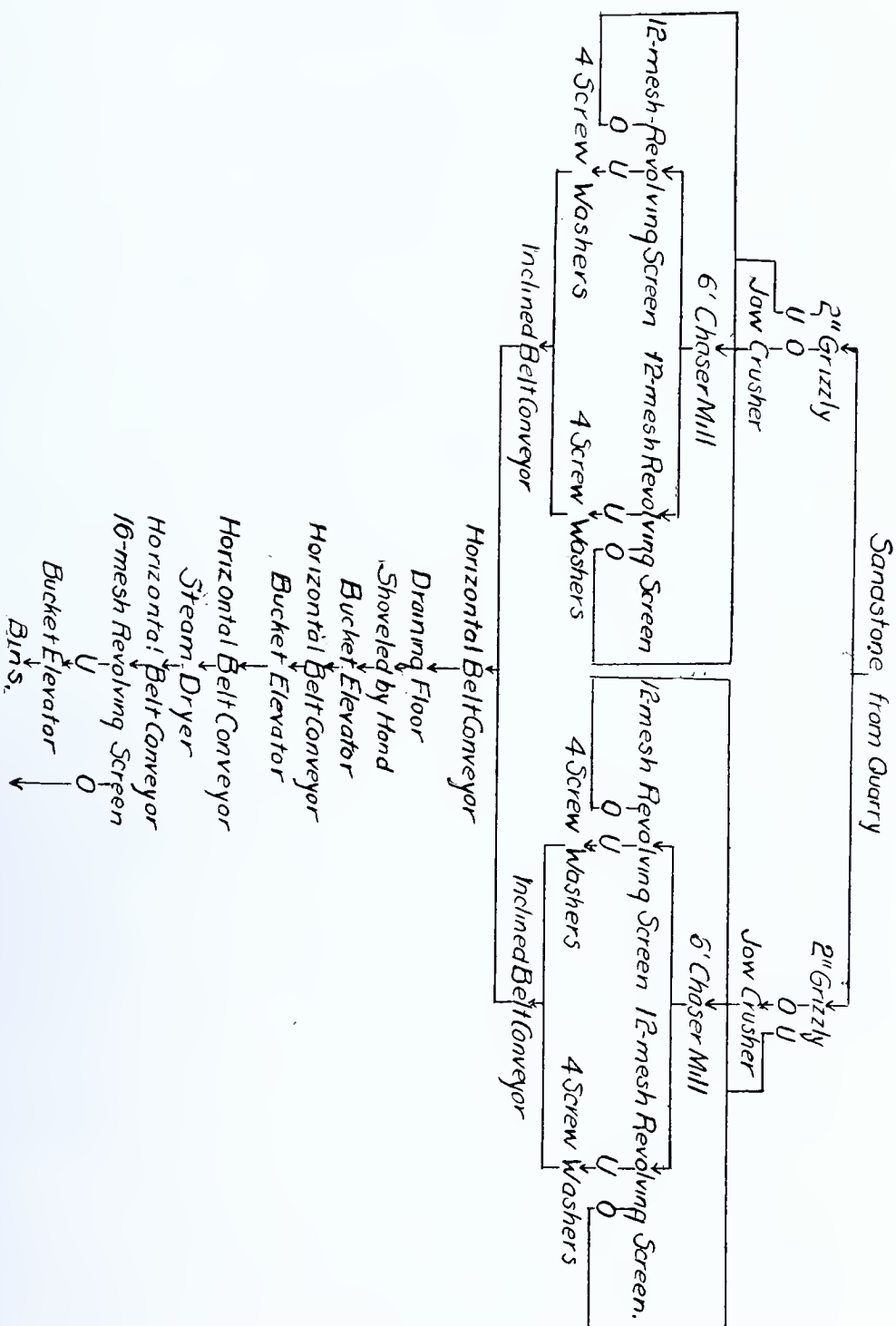a depth of about 125 feet below the outcrop. No underground mining is done, however the deposit being worked as an open quarry. The formation has been opened for a distance of 670 feet along the strike. The southwest 520 feet have been worked in two benches, the upper bench, with a maximum depth of about 75 feet, was taken out before the present tunnel was driven. This cut the sandstone 50 feet further down and about 190 feet of sandstone along the strike at the northwest end of the upper bench have been mined to this new level. The northeast 150 feet of quarry have been worked as one bench. The quarry has a width of 180 feet at the top at the northeast end, and 240 feet at the southwest. Figure 1, Plate LXXXVIII shows a view of the quarry looking northeast, Figure 2 one in the central portion, and Figure 3 one looking southwest.

The sandstone and sand are loaded into cars at the quarry and hauled to the mill by mules. The mill is equipped with three six foot chaser mills, and a steam dryer. Plate LXXXIX gives the flow sheet. It has a daily capacity of about 240 tons of sand. Only the sandstone can be used for preparing No. 1 sand, the loose sand containing so much limonite that it yields only No. 2 sand No. 3 grades. About one-third of the output of the quarry is sold as No. 1 sand, the balance being Nos. 2 and 3. The No. 3 sand is not passed through the dryer but is sold wet.

Crystal Sand Company.

About one mile southwest of the station of Vineyard on a short siding of the Pennsylvania railroad, the Crystal Sand Company is operating a sand plant of 200 tons daily capacity. The quarry is situated at the works on the same limb of the syncline on which the Enterprise quarry is located. The dip is a very gentle one toward the southwest. The rock encountered in this quarry is moderately hard, it being possible to disintegrate it only with difficulty between the fingers. The rock is badly fractured and some iron oxide stain occurs along practically all the joints thus developed, but does not penetrate the rock itself to any extent. The upper 8 feet or so of the formation contain large amounts of limonite and together with about two feet of soil have to be stripped. This is done by loading the material into wagons and hauling it to abandoned portions of the quarry or other places off of the outcrop that are convenient. The present working face is about 300 feet long and 30 feet high at the east end and 50 feet at the west. Figure 1, Plate XC shows a view taken in the quarry.

The plant is equipped with two chaser mills and the necessary jaw crushers, screens, screw washers, conveyors, etc. For preparing the sand a steam dryer is used for drying the sand. Plate XCI shows the flow sheet of this mill.

John Miller's Sand Mine at Burnham.

During the summer of 1914, John Miller, of Lewistown, erected a small sand washing plant on Kishickoquillas creek below Burnham to treat sand obtained from his mine about one mile northeast of this place. Loose sand is mined and therefore, no crushing machinery is necessary. Mr. Miller does not intend to dry any sand at first, but expects to sell it wet. Later on if he opens up considerable bodies of first class sand in his mine a dryer may be installed. The washing plant and mine are connected by a narrow gauge track, over which cars are run by a small electric motor.

The mine is located on the southeast limb of a syncline, the strata dipping gently to the northwest as is shown in Figure 1, Plate LXXXIII which is a cross section of the ridge in which the mine is situated. A tunnel has been driven into the hill for about 700 feet through the underlying shales to cut the sandstone at a depth of about 100 feet below its outcrop.

The sandstone of this limb of the syncline has been disintegrated to loose sand by the agents of weathering. As exposed in the caved openings along the outcrop over the mine workings it is seen to be a light yellowish brown in color and appears as though it ought to yield a No. 2 glass sand on washing. An analysis of a sample obtained here gave .18% Fe_2O_3. A size determination of the grains gave the following results:

Screen Analysis of Sand from John Miller's Mine, Burnham.

	Inches.	
Passed through a 14 mesh and caught on a 20 mesh sieve, _____	.0328	.02
Passed through a 20 mesh and caught on a 20 mesh sieve, _____	.0232	.21
Passed through a 28 mesh and caught on a 35 mesh sieve, _____	.0164	1.13
Passed through a 35 mesh and caught on a 48 mesh sieve, _____	.0116	10.48
Passed through a 48 mesh and caught on a 65 mesh sieve, _____	.0082	56.76
Passed through a 65 mesh and caught on a 100 mesh sieve, _____	.0058	25.43
Passed through a 100 mesh and caught on a 150 mesh sieve, _____	.0041	2.64
Passed through a 150 mesh and caught on a 200 mesh sieve, _____	.0029	1.30
Passed through a 200 mesh, _____	_____	1.58
		99.55

During the winter of 1914 the writer was informed by the officials of the McKee Glass Company of Jeannette, that they had used two carloads of sand from John Miller's plant and found it entirely satisfactory.

Undeveloped Areas.

One of the most promising occurrences of Oriskany sandstone in Mifflin County which is not as yet utilized for glass sand is the one opened up in the sand pit of the Standard Steel Company about 2 miles northeast of Burnham. Unfortunately there is a large amount of overlying shale and iron stained sandstone, so that underground mining methods would probably have to be used to recover the white sand. Most of the other outcrops of Oriskany in the area around

Lewistown, with the exception of the occurrence northeast of Burn-
ham, do not look very promising.

Bodies of white sandstone suitable for glass sand undoubtedly oc-
cur between the Juniata Mine at Granville and the Dull Mine at Mc-
Veytown. Some of this ground is already under the control of the
Pennsylvania Glass Sand Company, including one and one-half
miles of out crop northeast of the Dull mine, which this Company
expects to open up as soon as better railroad transportation facili-
ties are available.

Southwest of the Dull & Macklin mines the outcrop also has a
favorable appearance, especially beyond the creek which crosses the
outcrop on which the former are located, two miles southwest of Mc-
Veytown. A great difficulty here is the poor facilities for transpor-
tation, as this portion of the outcrop is located at a considerable dis-
tance from the railroad.

At Vineyard practically all the available sites for quarries are al-
ready utilized. On the whole the disintegrated sandstone in this
vicinity contains a little more iron in the form of limonite than that
at the other glass sand producing centers of the Juniata Valley, and
it also becomes fairly hard southwest of Vineyard where the forma-
tion lies nearly horizontal.

CHAPTER XVIII.

GLASS SAND DEPOSITS OF THE ORISKANY AGE IN OTHER PARTS OF CENTRAL PENNSYLVANIA.

Bedford County.

The outcrop of Oriskany sandstone along Warriors Ridge, in Huntingdon County, has already been described in a previous chapter dealing with the Oriskany of that county. This outcrop continues in a southwesterly direction through the whole length of Bedford County.

It was examined in some detail by the writer between Tatesville and Everett, where it has undergone considerable disintegration, and in many places crumbles readily to white or light yellow sand.

At Tatesville, which is about 3 miles north of Everett, a small stream has cut a gap across the Oriskany outcrop. The sandstone has a thickness of about 100 feet at this place and dips 30° to the southeast. The part which is well exposed here is a hard white quartzite, containing comparatively little iron oxide. South of this gap, however, portions of it begin to show disintegration, whch becomes more and more pronounced as the outcrop is followed away from the creek. The rock is free from iron stain and where it has disintegrated to sand this is almost white in color.

About one-half mile south of the gap at Tatesville, Calvin Ritchey has opened a quarry on land belonging to the Huntingdon & Broad Top Mountain Railroad and Coal Company. The sandstone at this place has, for the most part, been disintegrated to loose sand, varying in color from white to light yellow. An analysis of an average sample of unwashed sand from this quarry gave .10% Fe_2O_3. A sizing test gave the following results.

Screen Analysis of Sand, Ritchey Quarry, Bedford County.

Passed through 10 mesh and caught on a 14 mesh sieve,	.046	.11
Passed through 14 mesh and caught on a 20 mesh sieve,	.0328	.74
Passed through 20 mesh and caught on a 28 mesh sieve,	.0232	3.27
Passed through 28 mesh and caught on a 35 mesh sieve,	.0164	10.55
Passed through 35 mesh and caught on a 48 mesh sieve,	.0116	37.35
Passed through 48 mesh and caught on a 65 mesh sieve,	.0082	33.47
Passed through 65 mesh and caught on a 100 mesh sieve,	.0058	10.59
Passed through 100 mesh and caught on a 150 mesh sieve,	.0041	1.35
Passed through 150 mesh and caught on a 200 mesh sieve,	.0029	.64
Passed through 200 mesh sieve,		1.45
		99.52

This quarry has been opened for a distance of 150 feet along the strike and has a maximum height of 35 feet, with 1 to 2 feet of soil covering the sand. The ridge, on the west side of which the quarry is located, rises about 65 feet above the bottom of the quarry and on the quarry side has a slope of 28°. The formation drops 30° to the southwest, Figure 2, Plate XC shows a view looking north in this quarry.

At present the sand is mined with picks and shovels, and is loaded into wagons which haul it 200 feet to a siding on the Huntingdon & Broad-Top Mountain Railroad. Boulders of sandstone which are encountered are crushed into sand with hammers. The sand is sold largely to the Colonial Iron Company of Riddlesburg, the Earlston Furnace at Everett, and the Saxton Furnace at Saxton, for furnace sand. Some is also used locally for concrete. None of it is being sold for glass sand at present, although a good quality of glass sand could be produced from it by washing and drying.

Sand was at one time taken from this locality for an old glass works at Everett. It was used without washing or drying, and therefore was not found satisfactory, and sand was imported from Mapleton instead. Mr. H. F. Gump of Everett, who was interested in this glass works informed the writer that the sand they took out contained too much iron. It is very likely they happened to make an opening at a place where some iron bearing solutions had filtered in and locally precipitated limonite in the sandstone. Practically all the sand exposed in the present working face could on washing and drying be sold as No. 1 sand. Occasionally a little iron oxide has been brought in along a joint plane but this forms a relatively insignificant percentage and could be readily sorted out.

About 100 feet south of the above quarry is another one which has been opened for a distance of about 550 feet along the strike, with a maximum height of working face of 35 feet. Most of this sand as exposed is also either white or else only a light yellow in color and apparently of excellent quality. At several places some limonite has been deposited locally in the sand by circulating waters.

One and one-half miles south of Tatesville, along the ridge formed by the Oriskany outcrop, the sandstone has been uncovered for a short distance and some of it has been quarried for use in building a reservoir on the side of the ridge at this place. The rock is white in color and only moderately hard, resembling the sandstone at the Keystone and Columbia quarries at Mapleton in these respects. About one-fourth of a mile further to the south an opening about 500 feet long partially expose the Oriskany sandstone along its outcrop. As far as can be seen the sandstone has been disintegrated to loose sand and is comparatively free from iron oxides, so that it is practically white in color.

About one-half mile south of the above opening and one mile north of Everett, another sand pit has been opened along the Oriskany sandstone to supply the local demand for building sand. This pit is about 90 feet long and has an average depth of 20 feet. The ridge rises 60 feet above the bottom of this quarry and has a slope of $28\frac{1}{2}°$ on the west side in which the quarry is located. The sandstone dips

45° to the southeast. All of it crumbles readily to white or light yellow sand. Only occasionally is a little iron stain present along joint planes. From outcrop indications it appears that the upper portion of the formation, which has not been opened up as yet, is somewhat harder and less disintegrated.

Although no glass sand had been prepared from the Oriskany sandstone between Tatesville and Everett up to the time of the writer's visit in 1914, with the exception of a little for local use at a former glass works in Everett, excellent deposits of such sand are available at this locality. The only disadvantage is that in shipping to western Pennsylvania the sand would have to be sent over two railroads, namely, the Huntingdon & Broad-Top Mountain, and some other line, to destination which would involve higher freight rates than from points more favorably located.

Blair County.

According to Franklin Platt [54] the Oriskany sandstone reaches a thickness of only 20 to 50 feet in Blair county. It is highly fossiliferous and usually friable, decomposing rapidly into loose sharp sand at the surface. Platt reports the occurrence of a fine deposit of glass sand on the poor house farm one mile northwest of Hollidaysburg. The sand is clean and sharp and has been used for foundry purposes. This locality was not visited by the writer.

Carbon County.

Prof. B. L. Miller[55] in describing the Oriskany of Carbon County states that it consists of sandstone and conglomerates of resistant character that are responsible for Stony Ridge. These sandstones and conglomerates vary in thickness from 150 to 175 feet. The cementing material in mainly calcareous and its removal in many places has caused the rock to disintegrate. Sand quarries are abundant all along the ridge for many miles, the material being shipped to many point in the State for use as molding sand, concrete and other purposes. The silica frequently runs as high as 98%. In working the sandstone for sand, the places where the rock is most greatly decomposed are selected, and little crushing is required. The sand grains are usually well rounded. The color is white to light yellow.

Centre County.

In Centre County according to E. V. d'Invilliers[56] the Oriskany sandstone has a maximum thickness of not exceeding 130 feet. An outcrop occurs along the southeast margins of Boggs, Howard and Liberty townships, dipping toward the northwest at an angle of from

54. Second Geological Survey of Pennsylvania Report T, 1881, pp. 35-36.
55. Topographic and Geologic Survey of Pennsylvania Report No. 4, pp. 52-55.
56. Second Geological Survey of Pennsylvania Report T-4, pp. 292-293.

20 to 40°, which according to d'Invilliers, has weathered to friable white sandstone and loose sand suitable for glass working at a number of places. It was at one time quarried for this purpose to supply a glass works at Bellefonte.

Monroe County.

According to I. C. White[57] sand for glass working was at one time quarried from the Oriskany formation of Monroe county, in Hamilton township. Glass sand was for a long time obtained from the Oriskany on the summit of Godfrey's Ridge for a bottle glass factory at East Stroudsburg. The rock is a grayish white, rather coarse grained sandstone with many small pebbles, which have a darker appearance than the enclosing matrix. The rock was hauled seven miles to East Stroudsburg. It contained too much iron for window glass. There are a number of other places along the ridge where sand for bottle glass has been obtained. The formation has a thickness of from 150 to 200 feet.

57. Second Geological Survey of Pennsylvania, Report G-6, pp. 283-284.

CHAPTER XIX.

THE POTTSVILLE FORMATION.

The Pottsville formation comprises the lowermost of the four for-
mations into which the upper Carboniferous or Pennsylvania strata,
of western Pennsylvania have been divided, the others being the Alle-
gheny, Conemaugh, and Monongahela respectively. It is composed
of conglomerates, sandstones, shales, clays, including fire clays, coals
and limestones, with conglomerates and sandstones predominating.

Character and Distribution of the Pottsville Formation.

The Pottsville group has a widespread distribution over a large por-
tion of the Appalachian mountain and plateau provinces of the East-
ern United States. It underlies the anthracite coal measures of
eastern Pennsylvania and the later Pennsylvanian strata of western
Pennsylvania and adjoining parts of eastern Ohio, and extends south-
west through Maryland, West Virginia, Virginia, Kentucky and Ten-
nessee into northern Georgia and Alabama.

The group received its name from the town of Pottsville, which is
situated near the center of the Southern Anthracite Coal Field of
Eastern Pennsylvania, in Schuylkill County. In this vicinity it
reaches a total thickness of 1200 feet. At its base it is apparently
conformable with the Mauch Chunk shales of the Mississippian, or
Lower Carboniferous Period, the latter grading into the former
through the gradual intercalation of more and more conglomerate
beds. On top, the line between it and the overlying coal measures
has been drawn at the lowest workable coal in the type region at
Pottsville, known as the Twin or Buck Mountain bed[58]. The con-
glomerates in the lower portion of the Pottsville formation are pre-
vailingly greenish, feldspathic, and poorly cemented. Cross bedding,
indicative of current movement from the northeast, is conspicuous.
The relatively small amounts of shales and coaly matter in the type
section are for the most part contained in the middle third. Toward
the top the conglomerate material becomes lighter in color, on ac-
count of the predominance of quartz grains and pebbles. At the type
section near Pottsville a few thin coals occur in the formation, none
of which, however, are profitably workable. To the north of Potts-
ville on the other hand, on Broad Mountain, and to the west through-
out the Southern Anthracite Field, coals occur in greater develop-
ment, especially locally, and have been extensively mined. These
are known as the Lykens coals. Sometimes as many as six distinct
beds are present. David White has divided the Pottsville of the

58. David White. 20th Annual Report of the United States Geological Survey, Part II, 1898-99.

Southern Anthracite Field into four parts, namely: a Lower Lykens group, a Lower Intermediate division, an Upper Lykens group, an Upper Intermediate division, on the basis of the fossil flora found associated with these coal beds.

To the northward the Pottsville gradually becomes thinner. In the Western Middle Anthracite Field the average thickness is about 850 feet[59]. Near the western end of the field two workable coal beds occur in the formation. In crossing the Eastern Middle Field from the south toward the northeast, the Pottsville diminishes in thickness from 500 feet to about 200 feet. It also shows a decrease in the size of the materials composing it. The one coal bed found here in the conglomerate has locally a workable thickness. In the Northern Anthracite Field the formation has an average thickness of about 225 feet, but is thinner at either end than in the central portion of the field. The diminished coarseness of the material is very marked, and toward the northeast end of the field the pebbles in the conglomerate are much scattered and rarely exceed pea size. No coal beds of workable thickness are found. At Campbell Ledge, near Pittston, in the Northern Anthracite Field, the formation has a thickness of only 56 feet, and at its base, according to David White, contains a flora which is similar to that of the Upper Intermediate division of the Southern Field. The three lower divisions, therefore, are not represented here.

In the Broad-Top coal field of Huntingdon and Bedford Counties in South Central Pennsylvania, according to James H. Gardner [60] the Pottsville has a thickness of 192 feet and consists mostly of sandstone, with some interbedded carbonaceous shales which contain thin streaks of coal.

Section of the Pottsville in the Broad Top Coal Fields.

	Feet.
Sandstone (Homewood) hard, medium grained, micaceous, gray, but weathers reddish brown,	45
(Mt. Savage or Mercer Horizon ?)	2
Shale bituminous, carrying kidney-shaped siderite concretions in upper portions,	30
Sandstone (Connoquenessing?), hard, medium grained, micaceous, gray but weathers reddish brown,	30
Shale, carbonaceous with streaks of coal (Sharon?),	1
Sandstone, brown, gray, and greenish gray,	34
Concealed, probably sandstone,	25
Sandstone, gray, containing white quartz pebbles less than one inch in diameter,	10
Sandstone, similar to above, with thin layer of conglomerate lenses,	15
	192

The lower sandstone comes to rest with a disconformity on the Mauch Chunk shales of the upper Mississippian, indicating an erosion interval between the two.

59. Second Geological Survey of Pennsylvania, Final Report, Vol. 3, Part I, pp. 1853-1854. pp. 755-930.
60. Topographic and Geologic Survey of Pennsylvania, Report 10, 1913, p. 26.

In the central part of northern Pennsylvania, in Tioga and Potter counties, the Pottsville has a thickness of 260 to 300 feet according to M. L. Fuller[61] and can be divided into two members, the lower of which consists of 60 to 100 feet of white quartz conglomerate and sandstone, black shale, and fireclay with a three foot coal bed in the upper part. The lower member has been called the Olean or Sharon Conglomerate. The Olean conglomerate, from paleobotanic evidence, is known to belong to the upper division of the Pottsville of Eastern Pennsylvania. The fossil plants associated with the coal bed in the upper part of the formation indicate that the bed belongs to the Mercer horizon of the Pottsville. The Olean conglomerate lies disconformably upon the Mauch Chunk shale of the Mississippian Period. The Pottsville is the highest formation left by erosion in this area.

In Warren County[62] in northwestern Pennsylvania, the Pottsville has been divided into three members, namely:—a lower one known as the Olean conglomerate, a middle one called the Sharon shale member, and an upper one called the Connoquenessing sandstone. The Olean is a coarse conglomerate, being composed almost everywhere of well rounded pebbles of white quartz, ranging up to $2\frac{1}{2}$ inches in diameter, though for the most part measuring $1\frac{1}{2}$ inches or less. These pebbles are imbedded in a fine ground mass of quartz grains and are cemented by iron oxide and silica. This bed rests unconformably upon the Mississippian strata underneath, with overlap towards the north. The Sharon shale member consists of about 40 feet of dark shale with limonite nodules and a few thin sandstone layers. One or two thin seams of coal are also present. The Connoquenessing is uniformly a very coarse, saccharoidal, white quartz sandstone, with a few small pebbles in places. Poorly preserved plant stems are common in it. It reaches a thickness of about 100 feet in places, while sometimes it thins down to 20 feet or even less.

The Olean conglomerate does not extend as far south as Clarion County. In this county the Connoquenessing member comes to rest unconformably upon upon Mississippian strata. It is thick bedded, persistant, saccharoidal sandstone, which ranges in color from buff to white and is nonfossiliferous[63]. Some layers are not well consolidated and appear much like granulated sugar. On the whole the rock is very clean and free from everything but silica. The beds are more or less lenticular. In thickness the Conoquenessing sandstone ranges from 30 to 50 feet. Above it, in Clarion County, is a series of shales, thin coals, and clays which has received the name of Mercer shale, because in Mercer county these beds are a prominent part of the section and one of the coals is worked. In Clarion County it

61. United States Geological Survey, Folio 92, 1903.
62. United States Geological Survey Folio 172, 1910.
63. United States Geological Survey, Folio 178, 1911.

varies in thickness from 6 inches to 40 feet. The topmost member of the Pottsville in Clarion County is the Homewood sandstone, which averages about 40 feet in the thickness. In some cases, however, the member is represented by shale. As a rule, it is a clean, white, finely cross bedded, and loosely cemented sandstone.

The following section of the Pottsville has been measured by I. C. White in Mercer County in Western Pennsylvania[64]:

Pottsville Section in Mercer County, Pennsylvania.

	Feet.
Homewood sandstone,	50
Shales,	5
Iron ore,	2
Mereer limestone (contains marine fossils),	$2\frac{1}{2}$
Mercer upper coal,	$2\frac{1}{2}$
Shales,	25
Iron ore,	2
Mercer lower limestone (marine mollusca),	$2\frac{1}{2}$
Shales,	10
Mercer lower coal,	$2\frac{1}{2}$
Shales,	10
Iron Ore,	1
Shales,	5
Upper Connoquenessing sandstone,	40
Shales with iron ore,	10
Quakertown coal,	2
Shales,	40
Lower Connoquenessing sandstone,	30
Sharon iron shales,	30
Sharon coal,	4
Fire clay and shales,	5
Sharon conglomerate,	20
	301

In northern Ohio[65] conglomerate, or coarse grained sandstone, which has generally been called the Sharon conglomerate, and which is perhaps equivalent to the Olean conglomerate of southwestern New York and northwestern Pennsylvania, lies at the base of the Pottsville. On top follow the Sharon coal, the lower and upper Massilon sandstones, the lower and upper Mercer groups, and the Homewood sandstone. Dr. J. J. Stevenson regards the Massilon and Connoquenessing sandstones as equivalent.

Returning to Blair county in south central Pennsylvania, northwest of the Broad-Top mountain coal field, the Pottsville formation lies unconformably upon the Mauch Chunk shale of the upper Mississippian, and has a thickness of about 130 feet[66]. It is composed of two sandstone members separated by shale and fire clay. These are the Connoquenessing sandstone, the Mercer shale and clay, and the Homewood sandstone. The Connoquenessing member in this section is 80 to 100 feet thick and consists of a rather coarse, gray sandstone with small lenses or layers of gray sandy shale. Above the Connoquenessing are 5 feet of shale overlain by 9 feet of fire clay, at the top of which, partially included in the overlying Homewood

64. Second Geological Survey of Pennsylvania Report Q-3, 1880, p. 33.
65. Geological Survey Ohio, Bulletin No. 7, Fourth Series.
66. United States Geological Survey, Folio 133.

sandstone, are small pockets of coal, 2 inches thick.   Above the fire clay is the Homewood sandstone, coarse, massive and 15 feet thick. Neither the Connoquenessing nor the Homewood sandstone is conglomeratic in this section.

In southwestern Pennsylvania, in Fayette county[67] the Pottsville formation has a thickness of about 180 feet and can also be divided into three members, namely:—the Connoquenessing sandstone, the Mercer coal and shale, and the Homewood sandstone.   The Connoquenessing sandstone rests disconformably upon the Mauch Chunk shales.   It is usually less than 100 feet thick in this area.   In places it is a coarse conglomerate, but generally it is a coarse, irregularly bedded sandstone.   It frequently contains lenses of shale.   The Mercer shale member varies from 20 to 50 feet in thickness.   Irregular beds of sandstone occur in the shale and usually a thin streak of coal.   A study by David White of the fossil plant remains from this horizon has shown that this coal is the equivalent of the Mount Savage coal of Maryland.   The Homewood sandstone ranges in thickness from 30 to 80 feet.   The upper portion is generally conglomeratic.

In western Maryland at Swallow Falls[68] in Garret county, the following section of Pottsville is exposed:

Section of Pottsville at Swallow Falls, Maryland.

	Feet.	Inches.
Massive sandstone (Homewood),	50	0
Fire clay (Mount Savage),	4	0
Coal (Mount Savage),	3	0
Shale,	5	0
Sandstone,	5	0
Coal (Lower Mercer),	0	10
Conglomeratic sandstone (Upper Connoquenessing,	15	0
Black Shale,	2	0
Coal (Quakerstown),	1	6
Shale,	0	6
Concealed,	0	8
Massive conglomerate sandstone (Lower Connoquenessing),	15	0
Concealed,	60	0
Shale,	5	0
Coal (Sharon),	1	4
Shale,	0	6
Sandstone,	25	0
	314	4

Along Cheat River, in Preston County, in northern West Virginia, the following section of Pottsville has been measured by I. C. White[69]:

Section of Pottsville in Preston County, West Virginia.

		Feet.	Inches.
Sandstone, massive (Homewood),		60	0
Coal, { Coal, 0 feet 5 inches, Shales, sandy, 6 feet 0 inches, Coal, 4 feet 5 inches,		6	10
Shales, brown, sandy,		45	0
Coal, slaty,		2	0
Shales,		3	0

67. United States Geological Survey, Folio 82.
68. Maryland Geological Survey, Geology of Garrett County, p. 103.
69. West Virginia Geological Survey, Reports, Vol. 2, p. 614.

Sandstone, massive,	25	0
Sandstone, flaggy,	15	0
Sandstone, massive, grayish, white,	20	0
Sandstone, flaggy,	8	0
Shales, brown,	4	0
Sandstone, grayish white,	20	0
Shale, brown,	3	6

New River coal bed,
Coal,	0 feet 5 inches,
Shales, gray,	4 feet 0 inches,
Coal,	0 feet 4 inches,
Shales, sandy,	8 feet 0 inches,
Iron ore,	0 feet 6 inches,
Shales,	5 feet 0 inches,
Coal,	1 foot 0 inches,
Shales,	10 feet 0 inches,
Coal,	0 feet 4 inches,
Shales, sandy,	25 feet 0 inches,
Coal,	0 feet 6 inches,
55   1

Shales, brown,	20	0
Sandstone,	15	0
Shales, buff, sandy,	20	0
Sandstone, massive, pebbly,	20	0
Concealed,	20	0
	362	5

Mauch Chunk Red beds.

Passing southwards through West Virginia the Pottsville becomes much thicker. In southern Fayette and northern Raleigh Counties the following members are present[70]:

Pottsville in Fayette and Raleigh Counties, West Virginia.

	Feet.	
Nuttall sandstone lentil,	0 to	200
Sandy and argillaceous shale and sandstone (containing Harvey conglomerate lentil and Sewell coal near base),	600 to	625
Raleigh sandstone,	75 to	150
Berkley coal.		
Quinnimont shale, sandy,	180 to	200
Quinnimont coal.		
Sandstone and shale (Thurmond),	450 to	550
Total, exclusive of Nuttall lentil,	1,305 to	1,525

In southern Raleigh, northern Wyoming and Mercer Counties the section is as follows:

Pottsville in Southern Raleigh, Northern Wyoming and Mercer County, West Virginia.

	Feet.	
Sandy and argillaceous shale and sandstone containing Harvey conglomerate and lentil and Guyandat sandstone lentil,	650 to	700
Raleigh sandstone, coarse,	75 to	150
Berkley coal.		
Quinnimont shale,	200 to	225
Quinnimont soal.		
Sandstone and shale (Thurmond, with Pocohontas No. 3 coal near middle),	600 to	725
	1,525 to	1,800

South of the above locality, in southern Wyoming and Mercer Counties, West Virginia, in the Pocohontas region the Pottsville has the following development[71]:

70. United States Geological Survey, Folio 77, 1902.
71. West Virginia Geological Survey Reports, Vol. 2, 1902, p. 619.

Pottsville in Southern Wyoming and Mercer Counties, West Virginia.

	Feet.
Sandy and argillaceous shale and sandstone, _____650 to	700
Raleigh sandstone, coarse, _____	80
Quinnimont shale, containing thin sandstone and a few coal seams, ____	300
Sandstone, heavy beds at top and bottom, with some shale and coal seams, _____	380
Pocohontas No. 3 coal.	
Gray and green argillaceous sandstone and sandy shale, _____ __	360
	1,820

West of the above area in McDonald County, the general section of the Pottsville is as follows:

Pottsville in McDonald County, West Virginia.

	Feet.
Datson sandstone, coarse with sandy shale at base, _____	180
Bearwallow conglomerate, coarse sandstone, _____	60
Sandstone and shale with several important coal beds and Dismal conglomerate lentil near center of formation in western area, _____	490
Raleigh sandstone, sometimes conglomerate, _____	100
Sandstone and shale with many beds of workable coal, _____	700
Coal, Pocohontas No. 3.	
Sandstone and shale, with the beds of coal, _____	360
	1,890

Mauch Chunk red shales.

Further to the southwest, in the Cumberland Gap coal field of southeastern Kentucky, the Pottsville group consists of the following members[72]:

Pottsville in Cumberland Gap Coal Field.

	Feet.
Bryson formation containing one or two coal beds of workable thickness, _____	200
Hygnite formation, largely sandstone, coal beds at top and bottom, ___	460
Catron formation, largely sandstone, contains several coal beds, ____	300
Mingo formation, largely sandstone with several coal beds.	
Havre formation, mainly shale, although it also contains some sandstone, _____	600
Lee sandstone, _____	1,200
	2,760

Still further to the southwest, in north central Alabama, in the Birmingham district, the Pottsville reaches its maximum development. In the Cahaba coal field, east of Birmingham, it is represented by 5100 feet of strata, consisting largely of shales with interbedded coal seams and some sandstone. The sandstones predominate in the lower portion of the formation, which comes to rest on the Parkwood shales of the Mississippian Period. A siliceous sandstone member, 250 feet thick, forms the lower part of the group. It becomes conglomeratic at the base[73]. Although the rocks are probably for the most part of fresh water origin, yet the presence of marine fossils at certain horizons, from the bottom to the top of the formation, in the Warrior and Cahaba fields, shows that there were incursions of the sea at intervals during Pottsville time.

72. United States Geological Survey, Professional Paper 49, 1906.
73. United States Geological Survey, Folio 175, 1910.

Geologic History of the Pottsville Formation.

From the present distribution of the Pottsville formation and the thickness, composition, and relative age of its different members, some ideas may be obtained in regard to the conditions under which it was deposited. From the description of the sections from various portions of the area over which the formation is distributed it is seen that it consists largely of coarse, clastic, or fragmental sediments, such as sandstone and conglomerates, although in certain parts shales, with which coal seams are frequently associated, predominate. As a rule the formation is characterized by an absence of marine fossils. There are some exceptions, as in the case of the Mercer limestone and certain horizons of the Alabama Pottsville. The areas over which these occur and the vertical portions of the formation which they occupy are relatively speaking very small when compared with the total extent of the formation. Fossils of land plants, on the other hand, are comparatively abundant. Torrential cross bedding is common in many of the Pottsville sandstones and conglomerates. More or less lenticular shaped bodies of conglomerate in sandstone, and lenses of sandstone in shale, and vice versa, are also of frequent occurrences. These characteristics, in addition to the presence of numerous coal beds in some areas, point to a continental origin for the Pottsville formation, that is that the formation was laid down on a low lying plain by streams flowing across it from adjoining more or less mountainous areas. These streams deposited much of their load of sediment directly on the land in the form of large alluvial fans. The finer muds, however, were often washed out into large lakes and swamps which existed in the depressed portions, over the low lying plain on which the Pottsville was deposited. This plain was gradually subsiding throughout Pottsville time, which accounts for the great thickness of the formation in places. Occasionally the subsidence was more rapid than the rate of deposition. Then the sea from the southwest invaded the area for a time, and the remains of marine organisms accumulated in the sediments deposited underneath its waters. Stratigraphically speaking, the lowest or oldest members of the Pottsville are found in the Southern Anthracite region of Pennsylvania and in the Pocohontas region of southern West Virginia. Attention has already been called to the fact that the Pottsville of the Southern Anthracite Field has been divided on the basis of paleobotanical evidence into four divisions, namely: the Lower Lykens, the Lower Intermediate, the Upper Lykens, and the Upper Intermediate divisions. The Lower Lykens contain coal seams 4, 5 and 6 and is about 500 feet thick, the Lower Intermediate is about 150 feet thick, the Upper Lykens contains coal

seams 1, 2 and 3, and is about 300 feet thick, while the Upper Inter-
mediate has a thickness of 250 feet.

In southern West Virginia, and adjoining parts of Virginia, the
roof shales of the Pocohontas coal, which form the lower part of the
Clark formation of the Pottsville group of that section, contains a
flora which corresponds to the No. 5 coal of the Lower Lykens division
of the Southern Anthracite Field thus showing that the lowermost
beds of this section were deposited practically contemporaneously
with the lower beds in the Southern Anthracite Field of Pennsyl-
vania.

From the present distribution and nature of the outcrops it is
apparent that toward the close of Pottsville time sedimentation was
going on over an area extending from southern New York, southwest
to central Alabama, over a strip of territory embracing the anthracite
fields of Eastern Pennsylvania and extending nearly as far west as
central Ohio.   A large part of Pennsylvania, nearly half of Ohio,
practically all of West Virginia, portions of western Maryland, east-
ern Kentucky and Tennessee, southwestern Virginia and northern
Alabama and Georgia were covered by Pottsville sediments.   This
area, which has been termed the Appalachian Basin, was at that time
grdually subsiding, and sediments were accumulating over it at about
the rate at which subsidence was going on.   To the east of it was
an old land mass which had been furnishing sediments to this area
throughout much of Paleozoic time.   Land also existed to the north
and to the west.

Deposition started in over this area, first in the Southern Anthra-
cite Field of eastern Pennsylvania and in the Pocohontas region of
southern West Virginia, also in northern Alabama.   These are the
areas over which the Pottsville has the greatest thickness, and were
apparently the centers of greatest deposition.   With the gradual sub-
sidence of the Appalachian basin deposition spread out over a greater
and greater area until the maximum was reached at the close of the
Pottsville.   In the case of eastern Ohio, the lowest member, the Sharon
conglomerate, which contains the Sharon coal, corresponds in age to
about the No. 2 and 3 coals of the Upper Lykens division according
to David White.   The Mercer coal corresponds to about the No. 1
coal of the same division.   In the Northern Anthracite Field of
eastern Pennsylvania, at Campbell's Ledge near Pittston, the dark
plant bearing shales at the base of the Pottsville, which is only 56
feet thick here, also correspond to the No. 1 coal of the Upper Lykens
in age.

Sedimentation in Pennsylvania during Pottsville time began in
the Southern Anthracite Field and spread in a northerly and westerly
direction.   The Northern Anthracite Field was not reached until

about the time No. 1 coal of the Upper Lykens division was being deposited in the southern field. The land mass to the southeast which furnished these sediments must have been fairly rugged, as the Pottsville of eastern Pennsylvania consists largely of conglomerates. In northwestern Pennsylvania sedimentation began with the Olean conglomerate, which is probably the equivalent of the Sharon conglomerate of Ohio, and therefore, was deposited at about the time of coals No. 2 and 3 of the Upper Lykens. Sedimentation commenced in eastern Ohio and northern New York before it did in all portions of western Pennsylvania, because the Sharon and Olean conglomerate are absent over much of this area, thus making the Connoquenessing the lowest member.

Attention has already been called to the fact that the Pottsville is made up principally of a continental type of sediments, marine fossils being entirely absent in most cases. It was deposited over the low lying plain formed by the gradually subsiding Appalachian basin by streams which originated on the elevated areas surrounding it, and which flowed across it to the sea which probably existed off in a southwesterly direction. These streams deposited much of their sediment in the form of huge alluvial fans on this plain. During the greater part of the time deposition kept pace with the rate of subsidence, and the area remained above sea level. In the depression on this plain large lakes and swamps formed in which the deposition of the finer sediments, such as clays and shales occurred. Large deposits of peat accumulated in many of the swamps, which on later burial were converted into the Pottsville coals of today. Occasionally over portions of the area subsidence was a little more rapid than the rate at which deposition was going on, and the sea encroached on those parts of the plain thus submerged. At these times beds containing marine fossils were deposited. The two limestones of the Mercer horizon in western Pennsylvania are examples. The maximum area of deposition was reached at the close of the Pottsville.

After the deposition of the Pottsville, sedimentation continued with occasional interruptions over a large part of this area during the rest of Pennsylvanian time and on into the Permian. The Pottsville sediments thus became buried under a considerable load of overlying sediment which resulted in their consolidation and the conversion of the peat which had accumulated in its swamps into coal. At the close of the Permian most of the area under discussion, including eastern and central Pennsylvania, western Maryland, West Virginia, southwestern Virginia, eastern Kentucky and Tennessee, northwestern Georgia and northern Alabama, was involved in the orogenic disturbance which resulted in the folded structure of the Appalachian mountains. The strata of western Pennsylvania and eastern Ohio were

elevated vertically above sea level by this movement underneath the earth's surface, but were not titlted from their original horizontal position to any great degree. Since the close of the Paleozoic, the whole region has been undergoing erosion. Over considerable portions of the original area of deposition the Pennsylvanian sediments have been entirely stripped, while in other cases erosion has proceeded only down to the Pottsville, exposing it at the surface. Over the remaining areas the Pottsville is still buried underneath overlying strata.

CHAPTER XX.

POTTSVILLE GLASS SAND DEPOSITS.

Certain members of the Pottsville formation are at times sufficiently pure quartz sandstones to be available for glass making purposes. As a rule the Pottsville sandstones are all sufficiently friable to be readily crushed to sand either in wet or dry grinding pans. Quartz sandstones available for glass sand occur in the Pottsville of western Pennsylvania, eastern Ohio, and northern West Virginia, at numerous localities. No where, however, do they excel the Oriskany sandstone in purity, and as a rule they rarely are equal to it in this respect, so that most of the glass sand obtained from the Pottsville is used for plate, window, and bottle glass, especially the latter two.

In western Pennsylvania portion of the Homewood and Connoquenessing members of the Pottsville formation are in certain areas sufficiently pure quartz sandstone to yield glass sands suitable for the manufacture of plate, window and bottle glass. As a general rule more clayey material and iron bearing minerals are present in even the purest Pottsville sandstones than in the Oriskany of central Pennsylvania. Occasional flakes of muscovite mica are also of common occurrence. The clayey material is usually derived from decomposed feldspar grains present in the rock.

The following two analyses show the composition of a selected pure quartz sandstone from the quarry of the Pittsburgh Plate Glass Company at Kennerdell, in southern Venango County, and the composition of an average sample of sand produced by crushing the sandstone obtained in the quarry of the Fox Silica Sand Company at Doguscahonda, in central Elk county, respectively:

Analyses of Glass Sands from Pottsville Formation.

	Selected sandstone from quarry of Pittsburgh Plate Glass Company.	Average sample of unwashed sand from Fox Silica Sand Co.
SiO_2,	98.35	96.08
Al_2O_3,	1.14	2.35
Fe_2O_3,	.06	.37
MgO,	trace	.08
CaO,	.11	.18
H_2O,	.21	.67
TiO_2,	.14	.15
	100.01	99.88

Both of the above samples are from the Connoquenessing member of the Pottsville formation. The following screen analyses show the percentage of the various sized grains present in Pottsville sandstones from various localities in western Pennsylvania.

Screen Analyses of Pottsville Glass Sands.

	1.	2.	3.	4.
Remaining in 10 mesh screen,	.00	.00	.13	.00
Through 10 remaining on 14,	.42	.04	.76	.44
Through 14 remaining on 20,	.78	.08	1.63	.30
Through 20 remaining on 28,	2.18	.91	6.79	.59
Through 28 remaining on 35,	7.28	6.86	14.76	2.08
Through 35 remaining on 48,	30.75	30.33	30.65	8.27
Through 48 remaining on 65,	37.06	30.85	23.62	13.31
Through 65 remaining on 100,	19.93	17.85	15.61	44.49
Through 100 remaining on 150,	.85	3.97	3.91	22.55
Through 150 remaining on 200,	.10	2.12	1.19	5.95
Through 200,	.03	5.00	.75	1.35
	99.38	98.01	99.80	99.33

1. Crushed, screened, and washed sand from quarry of Pittsburgh Plate Glass Company at Kennerdell, south Venango County. Connoquennessing horizon.
2. Crushed dry, and screened sand from quarry of Fox Silica Sand Co., Doguscahonda, central Elk County, Connoquennessing horizon.
3. Crushed, screened, and washed sand from American Window Glass Co., at Derry Station, eastern Westmoreland County, Homewood horizon.
4. Crushed, screened and washed sand from quarry of Dunbar Furnace Co., Dunbar, in northern Fayette County, Homewood horizon.

The Pottsville sandstones for the most part have only been partially cemented by siliceous bond, so that they can be crushed comparatively readily into loose sand. Cementation has been considerably less than in the case of the unaltered Oriskany sandstones of central Pennsylvania.

In the discussion on the geologic history of the Pottsville formation it has been shown that most of its conglomerate and sandstone members were deposited as flood plain sediments and large alluvial fans by streams flowing from a more or less rugged land area, across a low lying, nearly level plain. In the case of some of the sandstones the sorting action was sufficiently perfect to result in the deposition of nearly pure quartz sands. Undoubtedly the nature of the rocks exposed to weathering and erosion on the land area which contributed these sediments played an important part in determining the nature of the sandstones laid down. Where sandstones and quartzites which already contained predominating amounts of quartz were the chief contributors, the resulting sandstones were nearly pure.

Sandstone beds deposited under these conditions are apt to show considerable variations both vertically and laterally. The coarsest material is deposited nearest the land area undergoing erosion, and along the stream channel nearest itself, while the fine muds and clays are deposited in lakes and swamps existing in the depressions be-

tween streams. On such a nearly level plain the streams will also frequently shift their channels. They will also split up into numerous distributaries on the alluvial fans formed. As a result beds of conglomerate may be encountered in the sandstones deposited under such conditions as well as lenses of shale. The sandstone members will not necessarily remain uniform in thickness over an extensive area, but will thicken and thin when followed laterally, and often will pinch out entirely, their places being taken by shales.

Comparatively speaking, therefore, it is only rarely that sufficiently pure beds of Pottsville sandstone are found suitable for glass sand. Entombed plant remains, which have been converted into coal, are also present at times, and render portions of the sandstone undesirable for glass making on account of the carbon content introduced.

The position of the sandstone with respect to the surface topography is another important factor which determines whether or not it can be utilized. In preparing glass sand from the Pottsville there is only a small margin of profit and, therefore, the sandstone must occur in such a position that it can be quarried as cheaply as possible. The amount and direction of the dip of the beds, if any, and the amount of cover which has to be removed, are important factors in determining whether a certain occurrence of otherwise suitable sandstone can be economically quarried or not. Transportation facilities and the distance to market are of course also factors of prime importance.

Preparation of the Sand for the Market.

Two methods are used in western Pennsylvania to prepare glass sands from the Pottsville sandstone for the market. In one case the sandstone is put through a jaw crusher and chaser mill or wet grinding pan, and is then run through screw washers, in a manner exactly similar to that used in preparing glass sands from the Oriskany sandstone of central Pennsylvania. Where the sand is of sufficient purity to be suitable for plate glass, or similar grades of glass, it is also dried. Often, however, as in the case of sand for window and bottle glass this is not done, the sand being shipped wet.

For the cheapest grades of glass sand washing is not resorted to. The sandstone is passed through a jaw crusher and then goes to a dry grinding pan, where it is crushed to loose sand. After it has been screened it is ready for the market. This method of preparing the sand, together with a description of the machinery employed, has already been taken up in a previous chapter under the head of Silica as a raw material in the manufacture of glass.

Examination of Undeveloped Areas.

All of the sandstone of sufficient purity to attract attention as being possibly suitable for glass sand in the Pennsylvanian strata of western Pennsylvania are, according to the writer's observations, confined to the members of the Pottsville formation. Therefore, in looking for available deposits of this type of sandstone in western Pennsylvania particular attention should be paid to the outcrops of this formation. As has already been stated, however, the Pottsville does not every where contain beds of sandstone sufficiently pure for glass making purposes.

When a bed of sandstone has been discovered, which as far as its appearance in the hand specimen is concerned looks favorable, chemical analyses of representative samples should be made, especial attention being paid to the iron content, as this is the most deleterious constituent that is apt to be present. A microscopic examination of the sand for mineral constituents, besides quartz, that may be present is also desirable, as is a furnace test of the sand where this is feasable.

A careful determination of the extent of the sandstone should be made before any extensive plant is erected to crush it. On account of the conditions under which the Pottsville formation was deposited, sandstone beds in it are apt to vary considerably within a comparatively short distance, both vertically and horizontally. A careful investigation should, therefore, be made to determine whether a large enough quantity of the pure sandstone is present to supply a plant for a sufficient length of time to warrant its erection. Some of the things that should be looked for in examining an area of Pottsville sandstone as a possible site for a glass sand quarry are the presence of conglomerate lenses in the sandstone, especially in the northwestern part of the state, likewise the presence of shale lenses and changes in the clay and iron oxide contents of the sandstone, both vertically and laterally along a face of exposed sandstone.

Occasionally thin seams of coal, distributed through the sandstone at particular horizons, may readily render portions of it unsuitable for glass sand. Variations like those indicated above may make large portons of a particular bed of sandstone undesirable for glass sand. The thickness of a particular sandstone member may also change rapidly.

The situation of the bed of sandstone with respect to the surface topography is another factor of extreme importance. If the bed dips from the horizontal, the amount should be carefully noted. In this case the cover of overlying strata, as the sandstone is followed down on the dip from the outcrop, may soon become so great as to make further quarrying operations out of the question, and in as much as underground mining operations are as a rule too expensive a method

for obtaining glass sands of the grade available from the Pottsville formation, such an occurrence would not be desirable for a glass sand quarry. Where the sandstone bed is horizontal, the amount of overlying material should be carefully determined in the area over which future quarrying operations will probably extend. There may be so much cover present that stripping will be too expensive to warrant the selection of that particular site for a quarry.

Transportation facilities and nearness to market are other factors of prime importance. When the sand is to be washed, the question of available water supply should be looked into, especially during the latter part of the summer and early fall. During the fall of 1914, the writer came across several plants that were operating at a very considerably reduced rate of production on account of the lack of a sufficient supply of water for washing the sand. This usually means a very appreciable loss to the company.

Distribution of the Workable Deposits in Pennsylvania.

Outcrops of the Pottsville formation are found in the following counties of western Pennsylvania: Armstrong, Beaver, Cambria, Clarion, Clearfield, Crawford, Elk, Fayette, Forest, Indiana, Jefferson, Lawrence, McKean, Mercer, Somerset, Venango, Warren and Westmoreland. Of these, as far as the writer has been able to learn, the following have sand quarries located within their boundaries at the present time that are producing some glass sand, or have had such quarries during the past: Clearfield, Elk, Fayette, Forest, Jefferson, McKean, Venango, Warren and Westmoreland. These quarries are described in the next chapter.

CHAPTER XXI.

DESCRIPTION OF THE GLASS SAND QUARRIES IN THE POTTSVILLE OF PENNSYLVANIA, BY COUNTIES.

Clearfield County.

In Clearfield County the Pottsville formation has a thickness of from 275 to 325 feet, and consists largely of cross bedded sandstones and shales. The upper bed is often conglomeratic in its nature and a coarse conglomerate is frequently found at its base[74]. Outcrops of this formation that contain sandstone beds of sufficient purity to be utilized for glass sand occur in the northwestern part of the county at Falls Creek.

In the northwestern portion of the town of Falls Creek, the Fitzpatrick Glass Company at one time operated a quarry for glass sand in the Pottsville sandstone. The sand was washed before being used. When this company ceased operations the quarry was abandoned and the plant dismantled. It was located on a spur of the Buffalo, Rochester and Pittsburgh railroad. The strata at this quarry lie almost horizontal, there being only a slight dip toward the southeast. To the northwest, along the Buffalo, Rochester and Pittsburgh railroad, in a cut, a shale with a thin seam of coal is exposed underneath the sandstone. To the southeast the sandstone passes underneath later strata.

A sketch showing the plan and approximate size of the quarry is given in Figure 1, Plate XCII. Considerable variation shows in the quality of the rock along the working face, as is shown in the diagram. The best grade occurs at the south end of the quarry. At this place there are one to two feet of soil overlying the sandstone. Thirty-eight feet of the latter are exposed in the working face, of which the upper nineteen are rather coarse in texture, while the lower nineteen are made up of medium to fine sized grains. The rock is white in color and contains only small amounts of clayey material. Here and there a little discoloration by limonite may be noticed.

Elk County.

Outcrops of the Pottsville sandstone occur over large portions of Elk County, and in many localities they are so situated as to make conditions favorable for quarrying operations. The strata underlying Elk County are almost horizontal and where sandstone members of the Pottsville cap the divides between the stream valleys,

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74. Second Geological Survey of Pennsylvania, Final Summary Report, Vol. 3, Part 1, 1895, p. 1868.

PLATE XCII.
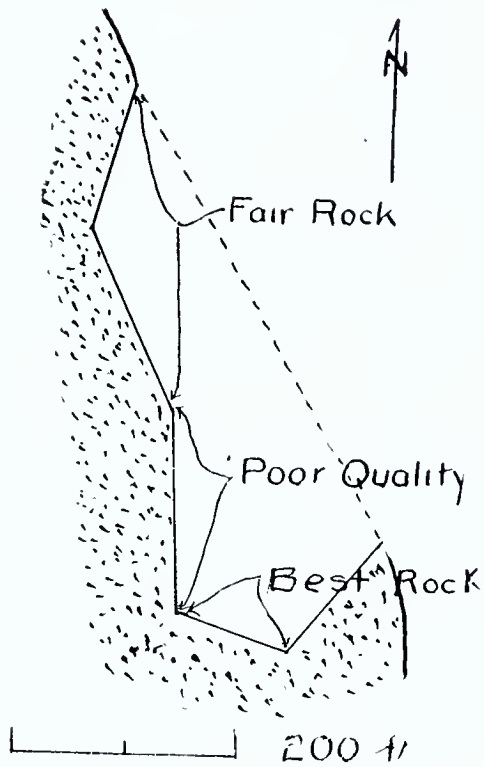
Fig. 1. Diagram of old quarry of Fitz-
patrick Glass Company, Falls
Creek, Pa.

Fig. 2. View in quarry of Fox Silica Sand and Stone Co., Daguscahonda, Pa.

as frequently happens, they are readily accessible for such operations. At St. Marys, in east central Elk County, the geologist of the Second Geological Survey of Pennsylvania, measured the following section of Pottsville strata:

<div align="center">Section of the Pottsville at St. Mary's.[75]</div>

	Feet.	Inches.
Johnson Run sandstone and shale (Homewood),	32	0
Alton upper coal bed,	2	7
Shale,	18	0
Alton lower coal,	3	0
Kinzua Creek sandstone (Connoquenessing),	45	0
Shale and coal,	10	0
Olean conglomerate,	50	0
	160	7

During the summer of 1914, four companies were operating sand plants in Elk county, namely, the Fox Silica Sand and Stone Co., the Ridgeway Sand and Stone Co., the Ridgeway-Croyland Silica Sand Co., and the White Silica Sand Co.

Fox Silica Sand and Stone Company.

The plant of the Fox Silica Sand and Stone Company, is located at the station of Daguscahonda on the Pennsylvania railroad, about half way between Ridgeway and St. Marys. The quarry is situated on top of the hill, on the north side of Elk Creek Valley. It is about 425 feet higher than the level of the railroad track at the plant. An old quarry of considerable size was at one time operated here for building stone.

At present all the sandstone quarried is crushed into sand. The present working face runs nearly north and south, and is about 250 feet long. At the southern end a lense of clay about 4 feet thick was encountered, which pinches out both in a northerly and southerly direction. At the north end of the quarry the following section was measured:

> 3 feet soil with pieces of broken sandstone.
> 3 feet shattered sandstone with some soil.
> 14 feet white quartz sandstone.

At the southern end of the quarry, where the clay lense referred to above pinches out, a working face 30 feet high is being developed. The clay lense contains abundant plant remains, as does also some of the sandstone directly below it. Much of the sandstone is distinctly cross-bedded.

Figure 2, Plate XCII shows a view taken in this quarry near the northern end of the working face.

The sandstone is blasted down and loaded into cars, which are hauled by a small steam locomotive about 800 feet along the hillside, to the head of a gravity incline. The cars are let down this incline

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75. Second Geological Survey of Pennsylvania, Final Summary Report, Vol. 3, Part I, p. 1881.

to the mill.   Dry crushing is employed and the sand is simply screened without washing.   Plate XCIII shows the flow sheet of the plant.   During the summer of 1914 an additional jaw crusher and 8 foot dry grinding pan were being installed.   Each of these pans has a daily capacity of 150 tons.   This brings the total possible output of the plant up to 300 tons per day.   The greater portion of the production is sold as glass sand, principally to window glass manufacturers.   Three grades of sand are produced, of which the first two are sold as glass sand, while the third or poorest, is sold for building purposes, etc.   An analysis of an average sample of the best grade of sand produced showed the following compositions:

Analysis of Glass Sand, Fox Silica and Stone Company.

SiO_2,	96.08
Al_2O_3,	2.35
Fe_2O_3,	.37
MgO,	.08
CaO,	.18
H_2O,	.67
TiO_2,	.15
	99.88

A screen analysis gave the following results:

	Per Ct.
Passed through 10 mesh, remained on 14 mesh, .046 inches,	.04
Passed through 14 mesh, remained on 20 mesh, .0328 inches,	.08
Passed through 20 mesh, remained on 28 mesh, .0232 inches,	.91
Passed through 28 mesh, remained on 35 mesh, .0164 inches,	6.86
Passed through 35 mesh, remained on 48 mesh, .0116 inches,	30.33
Passed through 48 mesh, remained on 65 mesh, .0082 inches,	30.85
Passed through 65 mesh, remained on 100 mesh, .0058 inches,	17.85
Passed through 100 mesh, remained on 150 mesh, .0041 inches,	3.97
Passed through 150 mesh, remained on 200 mesh, .0029 inches,	2.12
Passed through 200 mesh,	5.00
	98.01

Ridgway Sand and Stone Company, A. A. Urmann, Proprietor.

The plant of the Ridgeway Sand and Stone Company is situated about one and one-third miles east of Ridgway, on top of the hill on the north side of Elk Creek Valley.   It is connected with the Pennsylvania railroad by a long spur, which leaves the line between Ridgway and St. Mary's about three miles above Ridgway.

A practically horizontal bed of Pottsville sandstone caps the hill at this place.   This was at one time very extensively quarried for cut stone for masonry construction work and other building purposes.

At present all the stone taken out is crushed into sand.   Many loose boulders of Pottsville sandstone are scattered over the surface in the vicinity.   These are being largely utilized for the same purpose.   During the summer of 1914 rock was being quarried from the solid face at only one place.   Here a face about 200 feet long and 38 feet high with 3 feet of solid cover, had been opened up.   Figure 1, Plate XCIV shows its appearance.   Only selected portions of

Sandstone from Quarry

Chute

Dumping Floor

Shoveled by Hand

Jaw Crusher

8' Stevenson Dry Pan

Bucket Elevator

45° Inclined Stationary Screen 5-mesh. (12' long)

Chute   Belt Conveyor

Cars   Belt Conveyor

Stock Pile

PLATE XCIII.

Flow sheet of Fox Silica Sand and Stone Company's plant, Daguscahonda, Pa.

PLATE XCIV.

Fig. 1. View in quarry of Ridgway Sand and Stone Company, Ridgway, Pa.

Fig. 2. View in quarry of Ridgway-Croyland Silica Sand Company, Garovi, Pa.

the sandstone can be used for glass sand. A large percentage of the rock contains far too high an iron content to be suitable for glass making. As a rule the surface boulders run lowest in iron. The size of the grain varies considerably from place to place, both vertically and horizontally, but no conglomerate was noticed.

Two plants for crushing the sandstone, also located on top of the hill, about 500 feet above the level of Elk creek, are operated at this property. Each is equipped with a jaw crusher and an 8 foot Stevenson dry grinding pan. The sand is screened but not washed. Steam power is employed. Each mill has a daily output of 100 tons of sand. The company owns two small steam locomotives to haul the sand from these plant over a 3 mile siding to the Pennsylvania railroad along Elk creek. The siding and engine were part of the property of the company which formerly operated a building stone quarry at this site.

The output at present is largely sand and crushed stone for concrete, furnace sand, molding sand, grinding and polishing sand for plate glass manufacture, and a little second class glass sand.

Ridgway-Croyland Silica Sand Company, A. A. Urmann, Proprietor.

The plant of the Ridgway-Croyland Silica Sand Company, is located at Garovi station about one mile south of Croyland, on the Ridgway branch of the Pennsylvania railroad running to DuBois. The plant is situated along the railroad, while the quarry is up on the hill on the east side of the valley, at an elevation of 470 feet above the level of the track. The strata are practically horizontal at the quarry. A face of sandstone about 240 feet long, bearing N 17° E, has been opened up. The following section was measured near the middle of it:

Section at Quarry of Ridgway-Croyland Silica Sand Company.

3 feet soil.
10 feet conglomerate.
6 to 8 feet clay (a lenticular bed, pinches out at north end of quarry.)
.6½ feet fine grain sandstone.
1½ feet shale (lenticular. Pinches out at both ends of the quarry.)
29 feet nearly white sandstone with occasional thin seams containing pebbles. These however make up only very small parts of the bed.) Figure 2 Plate XCIV shows a view taken in this quarry. The sandstone is blasted down, loaded into cars and hauled a short distance by mules to the head of a gravity incline, which leads to the plant at the railroad. A jaw crusher and dry grinding pan are em-

ployed for crushing the sandstone into sand, which is then screened but not washed. The plant has a daily capacity of 100 tons of sand, very little of this sand, however, is sold for glass making. The conglomerate encountered in the quarry is crushed and sold for concrete work.

White Silica Sand Company.

The plant of the White Silica Sand Company is situated about four miles east of St. Marys, on the Pittsburgh, Shawmut and Northern railroad, along the northwest side of the track. Pottsville sandstone, lying nearly horizontal, forms the upper stratum on the northwest side of the hill. There are a considerable number of loose boulders scattered over the surface, although the sandstone itself is covered by 4 to 5 feet of soil. These surface boulders are gathered and sent to the mill to be crushed into sand. The difficulty with this method of obtaining sandstone is that a large amount of track has to be laid to get any great tonage of rock. Therefore, a site was being stripped during the fall of 1914 that a quarry could be opened in the bed rock itself. This is up on the hill, about three-fifths of a mile from the plant at the railroad. The sandstone is loaded into cars and hauled to the mill by mules.

Near the above site a small opening, about 50 feet square, was made during previous operations, but was later abandoned. The following was measured here:

Section, White Silica Sand Company Quarry.

	Feet.
Soil,	4
Coarse quartz sandstone containing some moscovite mica,	3
Sandstone containing abundant carbonized plant remains,	8
Coarse white sandstone,	3½
Fine grained sandstone,	3

Below this a sandstone with abundant plant remains was partially exposed.

On the whole the sandstone at this locality is not very favorably situated for conducting quarrying operations. The surface is nearly level for a considerable distance and difficulty will, therefore, be experienced in draining any quarry which is opened.

Considerable exploratory work is necessary to determine the nature of the sandstone underlying the area, as there are practically no outcrops of bed rock.

A small crushing plant has been erected. The sandstone is passed through a jaw crusher and then goes through a No. 18 Pulverizer, manufactured by the American Pulverizer Company of St. Louis. This has already been described in a previous chapter. After screening the sand is ready for the market. The machinery is run by a gasoline engine. The plant has a maximum output of about 50 tons

PLATE XCV.

View in quarry of Dunbar Furnace Company, Dunbar, Pa.

per day of ten hours. Very little sand has been sold for glass making purposes, most of it being used for concrete in building construction.

The Pottsville formation crops out at the surface along the flanks of two broad anticlines running in northeast and southwest direction across the eastern half of Fayette County. In this region it has a thickness of from 150 to 180 feet and consists of three members, namely, the Homewood, the Mercer and the Connoquenessing[76].

The highest, or Homewood member, is usually a massive quartz sandstone, varying in thickness from 30 to 80 feet. It is at times conglomeratic, but the pebbles are not abundant enough to be conspicuous. The Mercer shale member varies in thickness from 20 to 50 feet. At times it contains irregular beds of sandstone, and generally a thin streak of coal is present. The Connoquenessing does not exceed 100 feet in thickness, and is usually less than this, being exceedingly irregular in this respect. As a rule it is coarse, irregularly bedded sandstone, that frequently contains lenses of shale. In places a coarse conglomerate is also present. Of these three members, portions of the Homewood consist at times of sufficiently pure quartz sandstone to yield glass sand. Such sandstone has been quarried at a number of places in Fayette County. During 1914, two companies, the Dunbar Furnace Company, and the Yough Sand and Stone Company operated sand plants in this county.

Dunbar Furnace Company.

The sand plant of the Dunbar Furnace Company is situated above Dunbar creek, on a small tributary which enters that stream from the south, about three-fourths of a mile above the town of Dunbar. The quarry is located on the hill, east of the plant, in the Homewood sandstone member of the Pottsville, which at this place has a dip of 16° to the northwest. Figure 1, Plate XCV shows a plan of the quarry and Figure 2 is a view taken in the quarry to show the appearance of the present working face. This is about 540 feet long and 60 to 65 feet high. The cover of soil, which has to be stripped, nowhere exceeds 2½ feet. It is loaded into carts and hauled to one side. Some of the loose boulders of sandstone present in it are utilized for sand. The transition between the soil and the bed rock underneath is a sharp one.

Practically all of the present working face consists of massive white quartz sandstone. Much of it crumbles readily to sand when rubbed in the hand, especially after it has been exposed to the atmosphere for some time. Near the bottom of the working face thin streaks of coal are present locally, and the sandstone often contains abundant

76. United States Geological Survey, Folios 83 and 94.

carbonized plant remains, rendering it undersirable for glass sand. Here and there thin lenses of very coarse, almost conglomerate sandstone occur, but they are not present in sufficient quantity to be very detrimental. Some limonite stain occurs along the joint planes in places, and at times irregularly distributed through the sandstone, so that portions of the working face are rendered valueless for glass sand on this account. This, however, is not very wide spread. A platy sandstone of reddish color occurs at the north end of the quarry, being present as a thin capping at the north end of the present working face.

The sand is blasted down and loaded into cars which are hauled by mules to the head of a gravity incline, down which the cars are sent to the mill. This incline is about 1800 feet long and about 245 feet higher at the top than the level of the creek on which the plant is located. The sandstone is passed through a jaw crusher and wet grinding pan. It is then screened and passed through screw washers. None of it is dried at present, although, the plant is equipped with a Cummer dryer for this purpose. It is stored in stock piles outside of the mill building. The plant is equipped with three wet grinding pans.

At the time of the writer's visit during the fall of 1914 it was not in operation on account of a lack of sufficient supply of water to run the washers.

Glass sand and railroad sand are prepared at this plant. The former is used for making skylights, wire plate glass, window and other similar grades of glass. An analysis of an average sample of the best grade of glass sand produced showed .12% Fe_2O_3. This sand had a gray color with a light shade of brown. Here and there a grain of sand had a thin film of limonite adhering to it. Occasional specks of muscovite were also visible. A screen analysis gave the following results:

Screen Analysis of Glass Sand, Dunbar Furnace Company.

						Per Ct.
Passed through 10 mesh, remained on 14 mesh, .046 inches,					----------	.44
Passed through 14 mesh, remained on 20 mesh, .0328 inches,					----------	.30
Passed through 20 mesh, remained on 28 mesh, .0232 inches,					----------	.59
Passed through 28 mesh, remained on 35 mesh, .0164 inches,					----------	2.08
Passed through 35 mesh, remained on 48 mesh, .0116 inches,					----------	8.27
Passed through 48 mesh, remained on 65 mesh, .0082 inches,					----------	13.31
Passed through 65 mesh, remained on 100 mesh, .0058 inches,					----------	44.49
Passed through 100 mesh, remained on 150 mesh, .0041 inches,					----------	22.55
Passed through 150 mesh, remained on 200 mesh, .0029 inches,					----------	5.95
Passed through 200 mesh,					----------	1.35

99.33

Yough Sand and Stone Company.

The plant of the Yough Sand and Stone Company is located on a siding of the Western Maryland railroad, on the west side of the Youghiogheny River, a short distance above the point where a small

creek enters the former south of South Connellsville. The quarry is situated on a side of a hill about 135 feet above the mill, and is connected with the latter by a short gravity tram. The quarry was just being opened at the time of the writer's visit during the fall of 1914. At that time most of the rock crushed was taken from large talus boulders along the outcrop. The rock itself, however, was also well exposed. The Homewood member of the Pottsville is being opened up. While some of it is a white quartz sandstone, there are considerable portions that are colored a light yellowish brown by limonite. Inasmuch as the quarry is located on the hillside, and the rock dips into the hill, it will not be possible to quarry the rock any great distance back from the outcrop.

The plant is equipped with a No. 4 Blake jaw crusher and an 8 foot grinding pan, with double discharge. This mill has a daily capacity of about 200 tons. There are two batteries of three screw washers each, for washing the sand. This is shipped wet. The machinery is run by electric power. Water for washing the sand is pumped from the Youghiogheny River. During 1914 only one grade of sand was produced. This was sold largely as railroad sand, moulding sand, plasterer's sand, and building sand. One window glass factory was supplied with glass sand.

The Homewood sandstone has also been quarried for glass sand at other localities in Fayette County than the two above mentioned. A crushing plant was formerly in operation in South Connellsville, on the opposite side of the river from the present plant of the Yough Sand and Stone Company. Another abandoned quarry is located on the opposite side of Dunbar Creek from the plant of the Dunbar Furnace Company. A plant was also operated at one time on the east side of the Youghiogheny river about a mile above Layton.

Forest County.

Outcrops of the Pottsville occur over a large portion of Forest County. Sandstone members of this formation often cap the divide between the streams. When sand beds are of sufficient purity to be utilized for glass sand they make ideal sites for quarries. During 1914 there were no sand plants in operation in Forest County, but one company, the Spring Creek Glass Sand Company, was erecting a large up to date plant, and opening a quarry at Straits, in the southeastern part of the county, on Spring creek. This place can best be reached from Sheffield, over the narrow gauge Tionesta Valley railroad. The sand, however, will be shipped over a standard gauge track down Spring creek valley, which connects with the Pittsburgh, Shawmut and Northern railroad at Hallton.

Spring Creek Glass Sand Company.

The plant of the Spring Creek Glass Company is located on the east side of Spring creek valley, near the bottom of the valley, while the quarry is being opened upon the top of the hill above it. A sandstone member of the Pottsville forms the top stratum of the hills in this vicinity. In the case of the Spring Creek Glass Sand Company's property the bottom of the sandstone member in which the quarry is being opened is about 260 feet above the railroad track at the mill. Beyond the quarry site the hill rises very gradually for another 130 feet in elevation. The quarry and mill are connected by a gravity incline. Figure 1, Plate XCVI shows the appearance of the valley at the property of this company and Figure 2 shows a nearer view of the plant itself.

The sandstone and conglomerate member of the Pottsville formation, which caps the rather steep cliff forming the sides of the Spring Creek Valley in the vicinity of Straits, has, at the side of the Spring Creek Glass Sand Company's quarry, a thickness of 30½ feet. It lies practically horizontal. At the time of the writer's visit, during the fall of 1914, quarrying operations were just beginning. The upper 14½ feet of sandstone has been partially opened up along a face about 10 feet wide, and 4 to 5 feet deep. The rock exposure was a very pure white quartz sandstone. Only occasionally was a little limonite noticed along joint planes. No conglomerate was present at this point. The lower half of the formation had not been broken into, except in a large boulder which had become detached from the cliff. In this boulder it proved to be badly stained by iron oxide. No conglomerate was noticed in the sandstone at the site selected for the quarry, but only a short distance to the south, along the cliff, layers of conglomerate make up a large percentage of the formation. In places over half the total thickness consists of conglomerate. These conglomerate beds in the sandstone are very irregular. Usually they are not continuous, but lenticular in shape. Sometimes along the face of the cliff thin layers of conglomerate, one to two inches in thickness, are interbedded with the sandstone in such a manner as to practically render the entire thickness of the formation valueless for glass sand. North from the quarry site there is not very much conglomerate in the sandstone. Occasionally, however, pebbles up to one-fourth inch in diameter make up a prominent part of the formation. The site selected for the quarry is freest from such pebbles. East of the quarry the gradually upward sloping surface is dotted with numerous loose boulders of white, nearly pure white quartz sandstone, of excellent grade for glass sand. Usually only one foot or less of soil covers the sandstone. Excessive amounts of conglomerate and a rather high iron content in the lower portion of the sandstone

PLATE XCVI.
Plant of Spring Creek Glass Sand Co., Straights, Pa.

Sandstone from Quarry

12 X 20" Blake Jaw Crusher

9' Lewistown Chaser Mill.

12-mesh Revolving Screen   12-mesh Revolving Screen

O   U   U   O

4 Screw Washers   4 Screw Washers.

Inclined Belt Conveyor

Horizontal Belt Conveyor

Draining Floor.

Shoveled by Hand

Horizontal Belt Conveyor.

Inclined and Horizontal Belt Conveyor over Dryer

Steam Dryer

Horizontal Belt Conveyor,

Bucket Elevator

Revolving Screen

O   U

Storage Bins.

member in which the quarry is located, may cause some difficulty as quarrying operations proceed.

A modern sand plant has been erected at Straits by the Spring Creek Glass Sand Company. In it the sandstone is first passed through a 12x20 inch jaw crusher and then goes to a 9 foot Lewistown chaser mill, in which it is crushed to sand. Screw washers are employed for washing, and a steam dryer for drying the sand. It is expected that the plant will have an output of about 150 tons of washed and dried sand per day. The machinery is operated by a gas engine. A boiler has also been installed to supply the steam dryer. Plate XCVII shows the flow sheet of this mill.

Jefferson County.

Prominent outcrops of Pottsville sandstone occur in eastern Jefferson county, north of Falls Creek, along the line of the Buffalo, Rochester, and Pittsburgh railroad and the Ridgway Branch of the Pennsylvania railroad. During the summer of 1914 four sand companies, namely:—the Falls Creek Sand and Stone Company, the Gocella Stone and Sand Company, the Jefferson and Clearfield Stone and Sand Company, and the Silica Stone and Sand Company, were operating plants in this region. These companies are using sandstone from the same horizon as that which is exposed in the abandoned quarry at the Fitzpatrick Glass Company, at Falls Creek, in Clearfield county.

Falls Creek Stone and Sand Company.

The plant of the Falls Creek Stone and Sand Company is located about one and three-fifths miles north of Falls Creek, on a siding of the Buffalo, Rochester, and Pittsburgh railroad. The quarry is located on top of the hill at an elevation of about 125 feet above the level of the railroad at the mill. It is connected with the latter by a gravity incline about 1000 feet long. A working face 480 feet long had been opened up in a sandstone member of the Pottsville at the time of the writer's visit in 1914. The following section was exposed:

Section at Quarry of Falls Creek Stone and Sand Company.

Soil,	1
Broken rock with some soil (used for crushed stone for concrete),	3
Massive sandstone (upper 38 feet of medium grained texture; lower 12 feet coarse grained texture),	50

A considerable percentage of white quartz sandstone suitable for glass sand was exposed in the quarry face, but reddish streaks discolored by iron oxide are distributed irregularly through much of it, and other portions are stained brown by limonite, thus spoiling it for glass sand. Careful sorting would, therefore, be necessary in order

to use very much of the output of the quarry for glass sand. At present none of the output of the quarry is used for this purpose, although one or two trial cars of glass sand have been shipped which gave satisfaction.

The plant is equipped with a jaw crusher, a 9 foot Stevenson grinding pan, screens, bucket elevators, a boiler and an engine. A long steam pipe runs from the boiler at the plant to the quarry to supply steam to the machine drill. On account of excessive condensation of the steam this arrangement has not proven very satisfactory.

Gocella Stone and Sand Company.

The plant of the Gocella Stone and Sand Company is situated about 2,000 feet west of Harvey's Run Station, on a long spur of the Buffalo, Rochester, and Pittsburgh Railroad. Only a small quarry has been opened up, with a working face about 35 feet long. In it the following section was measured:

Section at Quarry of Gocella Stone and Sand Company.

	Feet.
Soil,	3
Medium grained sandstone,	5
Very coarse grained sandstone,	10
Fine grained sandstone,	7

A large amount of loose talus material occurs at this site, which has been drawn largely upon to supply the mill with sandstone. No glass sand has been produced, however, the output having been sold largely for furnace sand, engine and motor sand and building sand.

The plant is equipped with a No. 5 jaw crusher, and a 9 foot Stevenson dry grinding pan, together with the necessary bucket elevators, screens, etc.

During the writer's visit in September, 1914, the mill was not in operation.

Jefferson and Clearfield Stone and Sand Company.

The plant of the Jefferson and Clearfield Stone and Sand Company is located about one and one-fourth miles north of Falls Creek, on a siding of the Ridgway Branch of the Pennsylvania railroad. The quarry of the company is located at the top of the hill above the plant. It is about 135 feet above the level of the track at the mill and is connected with the later by a gravity incline. A quarry face about 200 feet long running nearly north and south, has been opened up. The following section is exposed:

Section at Quarry of the Jefferson and Clearfield Stone and Sand Company.

	Feet.
Broken stone with some soil (used for crushed stone for concrete,	8
Massive sandstone,	45

At the south end of the quarry the lower two-thirds of the sand-stone consists of nearly white quartz sandstone, while the upper one-third has a reddish tinge, due to the presence of iron oxides. At the north end the lower and upper one-third are white in color, while the middle one-third is reddish and contains some very coarse grained, almost conglomerate rock. This coarse rock pinches out toward the south end. Otherwise the rock is fairly uniform in texture. Some glass sand is produced. During 1914 two or three plants were being supplied. It was used for window and ribbed plate glass.

An analysis of an average sample of this sand gave .14% Fe_2O_3. A screen test showed the following sized grains to be present:

Screen Analysis.

		Per Ct.
Passed through a 10 mesh, remained on 14 mesh, .046 inches, _____		.28
Passed through a 14 mesh, remained on 20 mesh, .0328 inches, _____		2.11
Passed through a 20 mesh, remained on 28 mesh, .0232 inches, _____		8.75
Passed through a 28 mesh, remained on 35 mesh, .0164 inches, _____		16.56
Passed through a 35 mesh, remained on 48 mesh, .0116 inches, _____		31.95
Passed through a 48 mesh, remained on 65 mesh, .0082 inches, _____		18.58
Passed through a 65 mesh, remained on 100 mesh, .0058 inches, _____		11.75
Passed through a 100 mesh, remained on 150 mesh, .0041 inches, _____		3.53
Passed through a 150 mesh, remained on 200 mesh, .0029 inches, _____		2.13
Passed through a 200 mesh, _____ _____		3.74
		99.38

In the quarry the stone is loaded into carts which are hauled to the head of the incline by mules. Here the stone is dumped into cars which take it down to the mill.

It is the intention of the present operators to open another quarry along the cliff a short distance north of the present one, so that when blasting is going on in one quarry the men can be loading rock in the other.

The plant is equipped with a jaw crusher and a 9 foot Stevenson dry grinding pan for crushing the sand. The capacity is about 150 tons daily. The glass sand is passed over an 8 mesh, shaking screen. It is not washed.

Silica Stone and Sand Company.

The plant of the Silica Stone and Sand Company is situated about three-fourths of a mile north of Harvey's Run station, on a siding of the Ridgway branch of the Pennsylvania railroad. Thus far only talus boulders of Pottsville sandstone have been crushed into sand. No quarry has been opened. There are no prominent outcrops at this place, the sandstone being every where covered by a considerable thickness of soil. This will make the opening of a quarry a rather expensive proposition. No glass sand has been produced by this company.

The plant is equipped with a jaw crusher and a 9 foot Stevenson dry grinding pan, together with the necessary screens and bucket elevators, also an engine and boiler to operate the machinery.

McKean County.

The Sergeant Glass Company at one time obtained some glass sand from talus boulders of Pottsville sandstone occurring on the hill above its plant at Sergeant station, along the Pennsylvania rail-road, southeast of Kane, in southwestern McKean county. The sand-stone was passed through a jaw crusher, chaser mill, and one screw washer. No quarry was opened, as the outcrops of Pottsville in this vicinity are covered by a mantle of soil of considerable thickness. No sand is produced at this locality at present.

Venango County.

In southern Venango county the Pottsville formation has a thick-ness of from 120 to 130 feet[77]. It can be divided into three members, namely: The Connoquenessing, the Mercer and the Homewood sand-stone. The Connoquenessing is a thick bedded, resistant, saccharoidal sandstone, which ranges in color from buff to white, and is non fos-siliferous. Some layers are not well consolidated and appear much like granulated sugar. On the whole, the rock is very clean and free from everything but silica, so that it often can be used for glass sand. The beds as a rule are more or less lenticular. In thickness this member of the Pottsville ranges from 30 to 50 feet. In southern Venango county the Mercer member is represented by only 6 inches to 2 feet of coaly shale. The Homewood, or topmost member of the Pottsville, is a coarse grained, massive sandstone, averaging about 40 feet in thickness. It is generally a clean, white, finely cross bedded and loosely cemented sandstone.

During the summer of 1914, the Pittsburgh Plate Glass Company and the Venango Sand and Stone Company were operating sand plants in the vicinity of Kennerdell in southern Venango county.

Pittsburgh Plate Glass Company.

The sand plant of the Pittsburgh Plate Glass Company is located on the east side of the Allegheny River a short distance below Ken-nerdell, on a siding of the Pennsylvania railroad. The quarry is on the west side of the river and back some distance from it, on top of the upland into which the river has cuts its valley. It is connected with the plant by an aereal tramway, made by the Trenton Iron Company, now the American Wire Rope Company, which is little over a mile in length. This tramway has 44 buckets, of about 900 pounds capacity each, on it. In practice about 1200 buckets are run over it per twenty hours. In as much as the quarry is only operated 10 hours each day, storage bins have been built at the load-ing station, so that the tramway can be run for 20 hours, which is

77. United States Geological Survey Folio 178.

PLATE XCVIII.
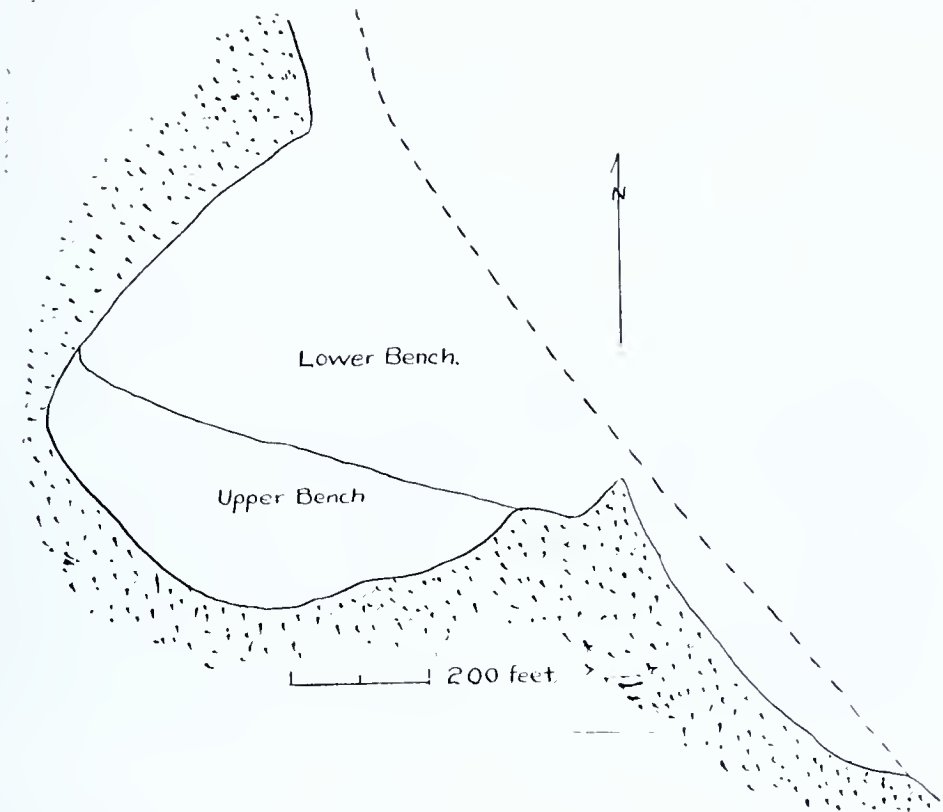
Fig. 1.   Diagram of quarry of Pittsburgh Plate Glass Company, Kennerdell, Pa.

Fig. 2.   View in main portion of the above quarry.

PLATE XCIX.

Fig. 1. Working face at southeast end of quarry of Pittsburgh Plate Glass Company. Kennerdell, Pa.

Fig. 2. Glass sand plant of Pittsburgh Plate Glass Company, Kennerdell, Pa.

Sandstone from Quarry   Sandstone from Quarry

Jaw Crusher   Jaw Crusher

6' Chaser Mill   6' Chaser Mill.

Revolving Screen   Revolving Screen

3 Screw Washers   3 Screw Washers.

Washed Sand   Overflow   Pipe   Centrifugal Pump   6' Chaser Mill.   Revolving Screen   Washed Sand

Belt Conveyor   Overflow   3 Screw Washers.

Storage Dump   Sump   Overflow

Wheelbarrows   Flume   Belt Conveyor

Cars   3 Screw Washers   Draining and Storage Shed

Belt Conveyor   Wheelbarrows

Molding Sand Pile.   Cars

PLATE C.

Flow sheet of glass sand plant of Pittsburgh Plate Glass Company, Kennerdell, Pa.

necessary to supply the crushing plant with sufficient sandstone. Some auxiliary power besides gravity is necessary to operate the tramway.

The floor of the quarry is about 400 feet above the level of the Allegheny river. Figure 1, Plate XCVIII is a diagram of the quarry while Figure 2, Plate XCVIII and Figure 1, Plate XCIX are two views taken in the quarry. Figure 2, Plate XCVIII showing a portion of the main quarry looking west and Figure 1, Plate XCIX showing the working face at the southeast end. At the southeast working face there are from 35 to 40 feet of practically horizontal Pottsville sandstone exposed, with 1 to 2 feet of soil. Most of the rock exposed in this face is a white quartz sandstone. Occasionally there is a little limonite stain along the joint cracks. An analysis of a selected specimen of the purer rock gave the following results:

Analysis of Pottsville Sandstone, Pittsburgh Plate Glass Company.

	Per Ct.
SiO_2,	98.35
Al_2O_3,	1.14
Fe_2O_3,	.06
MgO,	Trace.
CaO,	.11
H_2O,	.21
TiO_2,	.14
	100.01

At the southwest end of the quarry 30 feet of sandstone are exposed, with about 4 feet of soil resting on top of it. Below this is a lower bench which is being taken out in order to make the entire floor of the quarry uniform in elevation. One foot of very carbonaceous shale and six feet of light colored shale are exposed in this bench. This shale bed, however, is lenticular in shape, as it does not appear every where in the quarry at this horizon. Along some parts of the working face the rock is badly discolored by iron oxides and cannot be utilized for glass sand. This is particularly true of a portion between the southeast face and the main quarry as shown in the diagram. About 60 per cent of the total output of sandstone at this quarry is utilized for glass sand in the manufacture of plate glass. The rest is used chiefly for grinding and polishing sand.

The rock is blasted down and loaded into cars, which are hauled by mules to bins at the loading station of the aerial tramway. The intention, however, is to eventually arrange the tracks in the quarry in such a manner that one will run parallel to the working face, so that cars can be run along it, by means of a small steam locomotive. Air drills are used in putting down vertical holes from the top. The rock is usually quarried in two benches. The air compressor is run by a gas engine.

The crushing plant of the Pittsburgh Plate Glass Company during 1914 was equipped with two 9 foot chaser mills, as shown in the flow sheet given in Plate C, another unit, consisting of a jaw crusher, a 9 foot chaser mill, and six screw washers was being installed during the fall of 1914. This gives the plant a total capacity of 450 tons of sand per day. The sand is not dried at the plant, but is shipped wet to be dried later at the glass house. The machinery is housed in a steel frame building, with brick walls, concrete floors, and a sheet iron roof. The plant is equipped with engines and boilers to operate the machinery. Figure 2, Plate XCIX shows its external appearance. Water for washing the sand is pumped from the Allegheny river.

An analysis of a sample of the washed and dried glass sand prepared at this plant gave the following results:

Analysis of Glass Sand from Pottsville Formation, Pittsburgh Plate Glass Company Plant.

SiO_2,	98.71
Al_2O_3,	.35
Fe_2O_3,	.11
MgO,	None.
CaO,	.24
H_2O,	.16
TiO_2,	.05
	99.62

A screen test of this sand gave the following results:

Passed through 10 mesh, remained on 14 mesh, .046 inches,		.42
Passed through 14 mesh, remained on 20 mesh, .0328 inches,		.78
Passed through 20 mesh, remained on 28 mesh, .0232 inches,		2.18
Passed through 28 mesh, remained on 35 mesh, .0164 inches,		7.28
Passed through 35 mesh, remained on 48 mesh, .0116 inches,		30.75
Passed through 48 mesh, remained on 65 mesh, .0082 inches,		37.06
Passed through 65 mesh, remained on 100 mesh, .0058 inches,		19.93
Passed through 100 mesh, remained on 150 mesh, .0041 inches,		.85
Passed through 150 mesh, remained on 200 mesh, .0029 inches,		.10
Passed through 200 mesh,		.03
		99.38

Venango Sand and Stone Company.

This company is the successor of the Kennerdell Silica Sand Company, which in turn succeeded the Kennerdell Sand and Manufacturing Company. The plant of this company is located on a siding of the Pennsylvania railroad about one and three-fourths miles above the town of Kennerdell. The Pottsville sandstone is exposed at the top of a steep cliff rising about 440 feet above the level of the river. A quarry face about 150 feet long has been opened up, which exposed the following section:

Section at Quarry of Venango Sand and Stone Company.

	Feet.
Nearly white quartz sandstone,	15
Sandstone, with reddish color due to iron oxide,	30
Shale, with carbonaceous streaks near middle,	5
Nearly white quartz sandstone, upper few feet slightly reddish in color,	55

At present a new working face is being opened up on the lower bench of sandstone on the down stream side of the present opening. The heavy cover of overlying undesirable rocks makes this a rather poor location for a quartz sand quarry. Operations on the lower bench will necessarily have to be very limited, unless a large amount of waste material is to be handled. No glass sand is being produced at present, the sand being sold largely as furnace sand. The Kennerdell Sand and Manufacturing Company, however, when it operated this property sold some glass sand for making window glass, skylights and similar grades of glass.

The plant is equipped with a gyratory crusher, and rolls for crushing the sandstone to sand. After being crushed the sand is passed through three screw washers and run into a flume, down which it passes to the railroad cars below.

Warren County.

In Warren County the Pottsville formation consists of three members namely[78]: The Olean conglomerate at the bottom, the Sharon shale and the Connoquenessing sandstone at the top.

The Olean is a coarse conglomerate, composed almost every where of well rounded pebbles of white quartz, ranging in diameter up to $2\frac{1}{4}$ inches, although for the most part measuring $1\frac{1}{2}$ inches or less. These pebbles are imbedded in a fine ground mass of quartz grains, and are cemented by iron oxide and silica. In Warren County it has a maximum thickness of about 50 feet, thinning out toward the south.

The Sharon shale member has a thickness of about 40 feet, and is composed of dark brown shales, with limonite nodules and a few thin sandstone layers. The Connoquenessing is uniformly a very coarse, saccharoidal white quartz sandstone, with a few small pebbles in places. Poorly preserved plant stems are common in it. In thickness it ranges from 20 feet, or less, up to 100 feet. Outcrops of Pottsville sandstone are numerous in Warren County, but in 1914 only one sand Company, namely the Warren Silica Company, reported any production of glass sand. The plant of the Althom Sand Company, one of the other sand operators of this county, was destroyed by fire during the summer of 1914.

Warren Silica Company.

The mill of the Warren Silica Company is located near the depot at Torpedo, a station on the Dunkirk, Allegheny Valley and Pittsburgh Railroad, which is leased by the New York Central and Hudson River railroad and operated by the Lake Shore and Michigan Southern railroad. The quarry is located about one and three-fourths miles

78. United States Geological Survey, Folio 172.

from the mill and 265 feet above it on the upland of this portion of Warren County. It is connected with the mill by a narrow gauge railroad, owned by the company. At the quarry about 2 feet of soil occurs at the surface. Underneath this there are from four to thirteen feet of soil and broken rock, which is too iron stained to be of value for anything but the cheapest grade of sand. Below this lies a massive sandstone, varying in thickness from 12 to 25 feet. Most of this is a white quartzitic sandstone, which on crushing and washing yields a fairly good grade of glass sand. In places, however, it has a pinkish tinge, due to the presence of iron oxide. At present the floor of the quarry consists of a bed of shale. Figure 1, Plate CI, shows a diagram of the working face, and Figure 2, a view taken in the quarry. The quarry is about 680 feet long. An analysis of a sample of washed and dried sand showed the presence of .10% Fe_2O_3. It had a yellowish brown color. A screen test gave the following results:

Screen Test of Sand from Warren Silica Company Plant.

Passed through a	10 mesh and caught on a	14 mesh sieve,	.046 inches,	.25
Passed through a	14 mesh and caught on a	20 mesh sieve,	.0328 inches,	.27
Passed through a	20 mesh and caught on a	28 mesh sieve,	.0232 inches,	1.03
Passed through a	28 mesh and caught on a	35 mesh sieve,	.0164 inches,	5.80
Passed through a	35 mesh and caught on a	48 mesh sieve,	.0116 inches,	33.73
Passed through a	48 mesh and caught on a	65 mesh sieve,	.0082 inches,	34.62
Passed through a	65 mesh and caught on a	100 mesh sieve,	.0058 inches,	18.27
Passed through a	100 mesh and caught on a	150 mesh sieve,	.0041 inches,	3.32
Passed through a	150 mesh and caught on a	200 mesh sieve,	.0029 inches,	0.42
Passed through a	200 mesh,			0.29
				100.00

The sandstone at the quarry lies horizontal, and the quality of most of it is excellent, but the site has the great draw back, in that there is such a thick cover of soil and broken and partially disintegrated sandstone, badly stained by iron oxide, which must be removed, thus making quarrying operations very expensive. The partially disintegrated and iron stained sandstone can only be worked into the cheapest grade of sand. The plant of the Warren Silica Company is located near the Station at Torpedo. Plate CII shows its external appearance. The method of crushing the sandstone and washing the sand is somewhat different than that employed at other places. Instead of a jaw crusher a gyratory crusher is used. A Bartlett and Snow disintegrator of about 20 tons capacity per hour is employed to crush the broken sandstone into sand, in place of a chaser mill or wet grinding pan. Water is added to the sandstone in the disintegrator. The sand and water are run into long settling tanks. These are 36 feet long, 2½ feet wide and 5 feet deep, with flat bottoms. They are inclined at an angle of 1½° from the horizontal. On one side, near the bottom, four inch spigots are placed every 18 inches to draw off the sand. The waste water and fine clayey material held in suspension are allowed to flow off near the top at the

PLATE CL

Horizontal Scale �

Soil

Disinteqrated ss and soil

Disinteqrated Ss,

White Sandstone

Pink Ss

Horizontal Scale └──────┘ 100 feet.
Vertical Scale └─┴─┴─┴─┘ 20 feet.
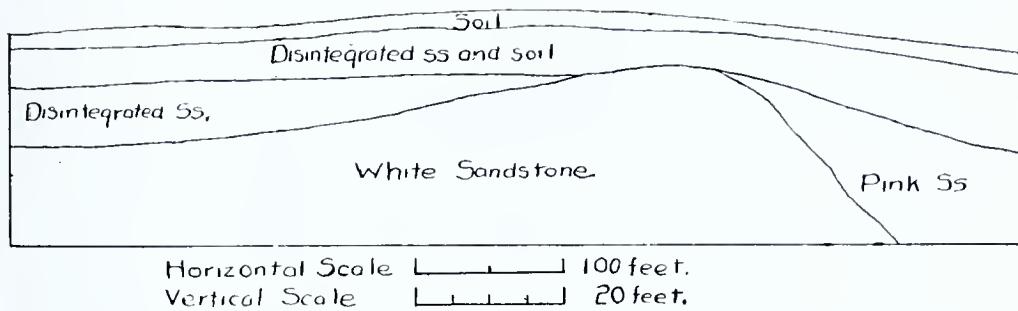
Fig. 1.   Diagram of working face at quarry of Warren Silica Co., Torpedo, Pa.

Fig. 2.   View in above quarry.

PLATE CII.

Plant of Warren Silica Company, Torpedo, Pa.

Sandstone in Cars from Quarry
Chute
Dumping Floor
5' diameter. Gyratory Crusher
Belt Conveyor
Water
Bartlett and Snow Disintegrator
8-mesh Revolving Screen
O   U
Waste Dump
6" Pipe

Grinding Sand, etc,   Glass Sand.

6" Pipe   6" Pipe.
Settling Tank   Settling Tank.(36'X 2½'X 5'deep)   Settling Tank
Overflow   Spigot Discharge   Overflow Spigot Discharge   Overflow   Spigot Discharge

Waste   6" Pipe   Hopper Bottom Bins   Hopper Bottom Bins
           Cars   Belt Conveyor
                                  Inclined Belt Conveyor

Cummer Dryer
Bucket Elevator
Chute
10-mesh Inclined Shaking Screen.
O   U
                 Horizontal Belt Conveyor
Bins   Srorage Bins,

PLATE CIII.

Flow sheet of plate at Warren Silica Company, Torpedo, Pa.

lower end. The plant is equipped with three of these tanks. A Cummer Dryer is used to dry the glass sand. Plate CIII, shows the flow sheet. The capacity is about 200 tons of washed sand per day. Only part of it is dried.

Althom Sand Company.

The plant of the Althom Sand Company was located at Althom, formerly called Thompson station, on the Allegheny Valley Branch of the Pennsylvania railroad. This plant was destroyed by fire during the summer of 1914. The quarry is located on the hill on the south-west side of Thompson run, about 480 feet above the level of the track at the former mill. It is connected with the latter by a gravity incline about 1400 feet long. There are three openings, each about 100 feet apart. In the southwest one of these a working face about 200 feet long has been uncovered. The following section was meas-ured near its center:

Section at Quarry of Althom Sand Company.

	Feet.
Soil grading into shale,	5
Massive sandstone,	18
Shale,	2
Sandstone,	1
Shale,	1
Sandstone,	2½ to 3½

The strata are practically horizontal. The shale beds are not of uniform thickness and in some places become more prominent than in others.

The middle opening, which contains the most shale, and is the poorest of the three, has a working face about 120 feet long. The northwest opening also has a working face about 100 feet long. Here the following section is exposed:

Section at Northwest Opening, Althom Sand Company's Quarry.

	Feet.
Soil,	4–8
Massive sandstone,	20

None of these openings show any large amounts of sandstone suit-able for glass sand. Of the three the northwest one looks the most promising. In the first, too much shale is present, and the sand-stone itself shows considerable stain by iron oxide. The heavy cover of soil is another draw back toward conducting quarrying operations at this site. During recent years only grinding and polishing sand for the plate glass industry was sold by the Althom Sand Company, at one time, however, the plant had also been equipped with a dryer, and some glass sand was produced.

Parthenum Silica Sand Company.

About one mile north of Althom, on the top of the hill along the west side of the river, is an abandoned quarry which was formerly

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operated by the Parthenum Silica Sand Company. This quarry is 500 feet above the level of the Pennsylvania railroad track at this place. It is located on the north side of the first creek entering the Allegheny River above Thompson Run on the west side. A quarry face about 300 feet long, running nearly east and west, was opened up. At the west end there are two feet of soil cover and 18 feet of massive sandstone, with a few thin streaks of conglomerate. Near the middle there are two feet of soil and 14 feet of massive sandstone, with practically no conglomerate, while at the east end, 2 feet of soil overlies 10 feet of massive sandstone, underneath which there are 8 feet of conglomerate. This conglomerate lense pinches out toward the west. It was left behind in the quarry as a bench. Most of the sandstone exposed is a white, nearly pure quartz sandstone. which is suitable for glass sand for window and similar grades of glass. It is of considerable better quality than that exposed in the quarry at Althom. The writer was informed that washed and dried glass sand was formerly produced from this quarry.

Westmoreland County.

In Westmoreland County outcrops of Pottsville sandstone occur along Chestnut and Laurel Ridges in the eastern part of the county. Along Chestnut Ridge[79] the formation has a thickness of from 75 to 170 feet. It consists of two beds of coarse sandstone namely: The Homewood and Connoquenessing, which are separated by 10 to 15 feet of sandy shale. In the vicinity of Derry, along Chestnut Ridge, the Homewood member of the Pottsville sandstone has been quarried for glass sand by the American Window Glass Company, and the Derry Glass Sand Company, while in the vicinity of Seward, in northeastern Westmoreland County, where the Conemaugh River crosses Laurel Ridge, the Connoquenessing sandstone member in places is sufficiently pure quartz sandstone to be suitable for glass sand.

American Window Glass Company.

The sand plant of the American Window Glass Company is located at the southeast end of the town of Derry, just beyond the town limits, on a small stream which has its source on the side of Chestnut Ridge. The sandstone quarry is located on the northwest side of Chestnut Ridge, on the north fork of this stream, about one and one-fourth miles above the mill. It is connected with the latter by a tram road. The quarry is about 465 feet above the mill in elevation, so that the cars can be let down by gravity. A hoisting engine has to be used, however, to assist in returning the empty cars. Five loaded cars are let down at one time, while five empty cars are being hoisted.

79. United States Geological Survey, Folio 110.

Sandstone from Quarry	Sandstone from Quarry	Sandstone from Quarry	Sandstone from Quarry
Jaw Crusher	Jaw Crusher	Jaw Crusher	Jaw Crusher
8' Chaser Mill	8' Chaser Mill	8' Chaser Mill	8' Chaser Mill
10-mesh Revolving Screen	10-mesh Revolving Screen	10-mesh Revolving Screen	10-mesh Revolving Screen
2 Screw Washers	2 Screw Washers	3 Screw Washers	4 Screw Washers
		Inclined Belt Conveyor	Sump
Sump			Nye Sand Pump
Nye Sand Pump			4½" Pipe
4½" Pipe			
Storage Shed		Draining and Storage Shed	
Wheelbarrows,		Wheelbarrows,	
Cars.		Cars.	

PLATE IV.

Flow sheet of glass sand plant of American Window Glass Company at Derry, Pa.

PLATE CIV.
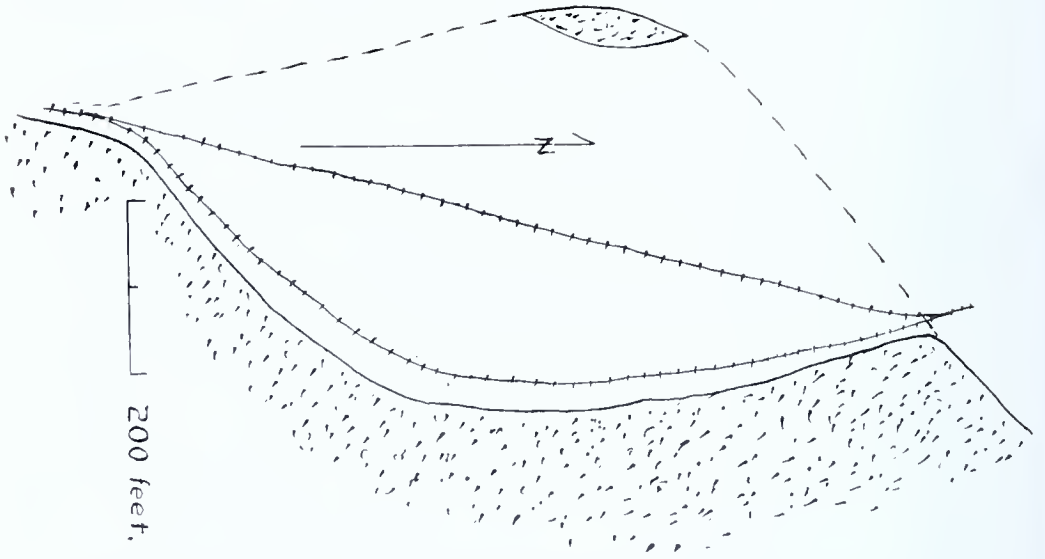
Fig. 1. Diagram of glass sand quarry of American Window Glass Company, Derry, Pa.

Fig. 2. View taken in above quarry.

A working face of about 1000 feet long has been opened in this quarry. Figure 1, Plate CIV shows a diagram of the quarry, while Figure 2 is a view taken in the quarry. Five feet of soil and 25 feet of nearly white, but rather hard, quartz sandstone occur at the south end. Near the middle there are from six to seven feet of soil, forty-five feet of nearly white sandstone, quartz sandstone, and fifteen feet of clay and sandstone, badly stained by iron oxides and containing some thin, irregular streaks of coal. At the north end there are five feet of soil and forty-five feet of white quartz sandstone. The best grade of rock is at this end of the quarry. Sometimes the sandstone is stained pretty badly by limonite along bedding and joint planes. Only rock is sent to the mill. About one-half of the sand prepared from the output of the quarry is used in the manufacture of window glass by the American Window Glass Company, the rest is sold as grinding sand to plate glass manufacturers. A sample of glass sand prepared at this plant showed .25% Fe_2O_3 on analysis. This sand has a very light brown color and contains occasional grains with coats of limonite adhering to them. A screen test gave the following results:

Screen Analysis of American Window Glass Company's Sand.

Passed through 8 mesh and caught on 10 mesh, .065 inches,	_____	.13
Passed through 10 mesh and caught on 14 mesh, .046 inches,	_____	.76
Passed through 14 mesh and caught on 20 mesh, .0328 inches,	_____	1.63
Passed through 20 mesh and caught on 28 mesh, .0232 inches,	_____	6.79
Passed through 28 mesh and caught on 35 mesh, .0164 inches,	_____	14.76
Passed through 35 mesh and caught on 48 mesh, .0116 inches,	_____	30.65
Passed through 48 mesh and caught on 65 mesh, .0082 inches,	_____	23.62
Passed through 65 mesh and caught on 100 mesh, .0058 inches,	_____	15.61
Passed through 100 mesh and caught on 150 mesh, .0041 inches,	_____	3.91
Passed through 150 mesh and caught on 200 mesh, .0029 inches,	_____	1.19
Passed through 200 mesh,	_____	.75
		99.80

During the fall of 1914 some of the soil cover was being simply shoveled back from the working face onto ground from which it will later have to be removed if operations are continued at this site. Some of the soil is loaded into carts and dumped into worked out portions of the quarry. The rather thick cover of soil, the worthless nature of that part of the rock appearing along the lower portion of the working face near its center, and the iron stained character of much of the white rock, are all rather serious drawbacks, which detract considerably from the value of this quarry as a desirable source of glass sand.

The plant is equipped with four eight-foot chaser mills, each of which has a daily capacity of 200 tons of sand. This gives the plant a total capacity of 800 tons of sand per day when all the mills are in operation. Three of them are run by steam power, while the fourth is operated by an electric motor. Plate CV shows the flow sheet for

this plant. The sand is all shipped wet, none of it being dried, although the plant is equipped with a Cummer dryer.

Water for washing the sand is obtained from three deep wells, two of which are down 450 feet while the third has a depth of 500 feet. All the water from the small creek at the mill which the town of Derry does not require is also utilized. During the fall of 1914 a shortage of water necessitated the shutting down of a portion of the plant.

Derry Glass Sand Company.

The plant of the Derry Glass Sand Company is located on a siding of the Pennsylvania railroad, about half way between Derry and Millwood, where a small stream cuts down the side of Chestnut ridge. During the fall of 1914 the Company was preparing to abandon its old quarry. A new one was being opened near the top of Chestnut ridge, a little over two miles southwest of the plant. This site is about 970 feet in elevation above the mill. Explorations have shown the presence of a thickness of about 45 to 50 feet of nearly white, massive quartz sandstone, with only three to four feet of cover. At the time of the writer's visit, in September, 1914, development work was just beginning at this place.

The old quarry is about 136 feet lower down on the side of the ridge. The sandstone at this place dips $8\frac{1}{2}°$ to the northwest. Therefore, as the quarry was opened in a southeast direction, back into the hill, the white quartz sandstone rose higher and higher, until finally it gave out. Figure 1, Plate CVI shows a view in the quarry, illustrating this condition. A bed of shale and dark colored sandstone, with occasional streaks of coal, underlies the white quartz sandstone. It was not feasible to continue operations at this site along the strike on account of existing topographic features and the increase in soil covering overlying the sandstone. For these reasons the quarry will be abandoned.

The sandstone is loaded into cars which are let down an inclined tramway leading to the mill. An electric hoist is used to assist in returning the empty cars. The air compressor at the quarry, to operate the drills, is also operated by electric power.

The plant is equipped with two six-foot chaser mills, of 125 tons capacity each, giving the plant a total capacity of 250 tons of sand per day. Plate CVII gives the flow sheet of this plant, and Figure 2, Plate CVI is a view showing its outside appearance. All of the sand is shipped wet. No glass sand is shipped at present, although sand suitable for the manufacture of window glass can be prepared.

Millwood Glass Sand Company.

The plant of the Millwood Glass Sand Company is located on a small creek at the station of Millwood on the Pennsylvania railroad.

PLATE CVI.

Fig. 1.   View in old quarry of Derry Glass Sand Company, near Derry, Pa.

Fig. 2.   Plant of Derry Glass Sand Company at Derry, Pa.

The quarry is located about 2000 feet up the valley of this creek, on the northeast side. A narrow gauge track, with a sufficient gradient to allow the loaded cars to run by gravity, connects it with the mill. Mules are used to haul the empty cars back to the quarry.

A quarry face about 60 feet long, with maximum height of about 25 feet, has been opened. There are from two to two and one-half feet of soil overlying the sandstone. The upper one-half of the sandstone is badly fractured and considerably discolored by iron oxides, while the lower one-half is a nearly white quartz sandstone. It is rather hard. The depth of cover will probably increase as the face is worked back into the hill.

The plant is equipped with a jaw crusher and seven-foot chaser mill. The latter has a capacity of 80 tons of sand per ten hours with the type of rock quarried. Four screw washers have been installed. The machinery is operated by electric power. Only building and grinding sand have thus far been prepared.

On the west flank of Laurel Ridge, in the vicinity of Seward, in northeastern Westmoreland county, the Connoquenessing member of the Pottsville formation consists of a friable quartz sandstone suitable for certain grades of glass sand, such as that used in the manufacture of window and bottle glass. The following analysis of a sample from this locality, made by A. J. Phillips, is quoted by W. C. Phalen in Folio 174 of the United States Geological Survey.

Analysis of Sand from Near Seward, Westmoreland County.

SiO_2,	97.54
Al_2O_3,	.81
Fe_2O_3,	.09
MgO,	.06
CaO,	1.04
Na_2O,	.02
K_2O,	.16
H_2O at 100,	.03
Ignition loss,	.49
	100 24

The writer did not have the opportunity to visit this locality.

CHAPTER XXII.

OTHER GLASS SAND DEPOSITS IN PENNSYLVANIA.
River Terrace Sand.

Sand for glass making has been obtained from deposits occurring along the abandoned channels of the Monongahela and Youghiogheny Rivers in southwestern Pennsylvania[80]. River sand of this type was formerly secured from the terrace opposite Bellevernon[81] and from the old valley back of the same town. These terraces were formed by the Monongahela river during the Pleistocene epoch, and were later abandoned. A similar deposit was at one time worked at Perryopolis on the Youghiogheny River. These sands are generally of very poor quality, on account of the high iron content, and were, therefore, only utilized in the manufacture of the cheaper grades of glass, such as bottle glass. At the present time no glass sand is being derived from these deposits.

The Tuscarora Sandstone as a Possible Source of Glass Sand.

The Tuscarora sandstone of central Pennsylvania (the so-called Medina of the Second Geological Survey of Pennsylvania) has attracted some attention as a possible source of glass sand. It is frequently a very pure quartz sandstone, analyzing over 98% silica, but it is usually very thoroughly cemented and recrystallized into a vitreous quartzite, which is extensively quarried in central Pennsylvania as ganister for the manufacture of silica brick. This rock on crushing does not break up into its component grains, as does a desirable sandstone for glass sand, but instead it breaks into fragments of various sizes, often across the grains themselves instead of along their contacts. In reducing these fragments to the size necessary for glass sand a great deal of fine powder is produced, and the operation is an expensive one, as compared with the crushing of ordinary sandstones.

Another peculiarity of the Tuscarora sandstone, as compared with the Oriskany, is that the former does not weather as readily to a friable sandstone or loose sand as does the latter, although such action does take place to a certain extent. J. P. Lesley[82] has called attention to such an occurrence along Blue Mountain, in Schuylkill County, near Drehersville, where white sand had collected along the crest of the mountain through the disintegration of the more loosely grained layers of the Tuscarora sandstone. These sands furnished silica for glass manufacture.

80. United States Geological Survey, Folio 82, p. 21.
81. United States Geological Survey, Folio 94, p. 19.
82. Second Geological Survey of Pennsylvania, Report F, page xxxi.

The Tuscarora in the vicinity of Hyndman, in south central Pennsylvania, along the main line of the Baltimore & Ohio Railroad, is an exceptionally pure quartzite and has, therefore, attracted some attention as a possible source of glass sand. An analysis of a sample collected from an abandoned ganister quarry on the hill above the Pennsylvania railroad bridge at this locality showed the following composition:

Analysis of Tuscarora Sandstone from Near Hyndman, Penna.

SiO_2,	99.54
Al_2O_3,	.35
Fe_2O_3,	.09
MgO,	.06
CaO,	.19
H_2O,	.25
TiO_2,	.03
	100.51

The formation dips 25° to the northwest and a thickness of 80 feet of the sandstone is exposed. With the exception of several thin shale seams the formation is a surprisingly pure white quartzite. If it were not for its hardness this rock would undoubtedly yield a good grade of glass sand.

The Silica Sand Company of Pittsburgh, a number of years ago, opened a quarry for glass sand in the Tuscarora sandstone on the west side of Cacapon Mountain in West Virginia, one and one-half miles west of Berkley Springs, on the road to Great Cacapon. A pit 20 feet wide and 150 feet long was quarried into the face of the hill, and an up-to-date sand plant for treating the sandstone was erected. The enterprise had to be abandoned, however, on account of the great hardness of the quartzite[83]. G. P. Grimsley gives the composition of the quartzite as follows:

Analysis of Tuscarora Quartzite from Caeapon Mountain, West Virginia.[84]

SiO_2,	99.86
Al_2O_3,	.23
Fe_2O_3,	.06
	100.15

It is not likely that the Tuscarora sandstone will yield any large amounts of glass sand in Pennsylvania in the near future, since large quantities of more desirable sandstones, equally favorably situated, are still available. A very careful and detailed investigation should always be made by parties contemplating the erection of a plant to produce glass sand from the Tuscarora sandstone, before any large sums of money are spent in purchasing property and equipment as in most cases it will probably be found that the quartzite is not suitable for crushing economically into glass sand.

83. United States Geological Survey. Folio 179, p. 21.
84. West Virginia Geological Survey, Volume 4, p. 396.

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INDEX

A.

GLASS PLANTS AND GLASS SAND QUARRIES IN PENNSYLVANIA

GLASS SAND QUARRIES

GLASS MANUFACTURING PLANTS

LEGEND

In Oriskany Sandstone.

In Pottsville Formation.

Pressed and Blown Ware.

Window Glass Factories.

Polished Plate Glass.

Scale